ILC Muon System R&D

Muon Detector Physics Motivation

Muon Detector Requirements

Physics/Detector Simulation

Detector Technologies

Scintillator-based Muon Detector

R&D Progress

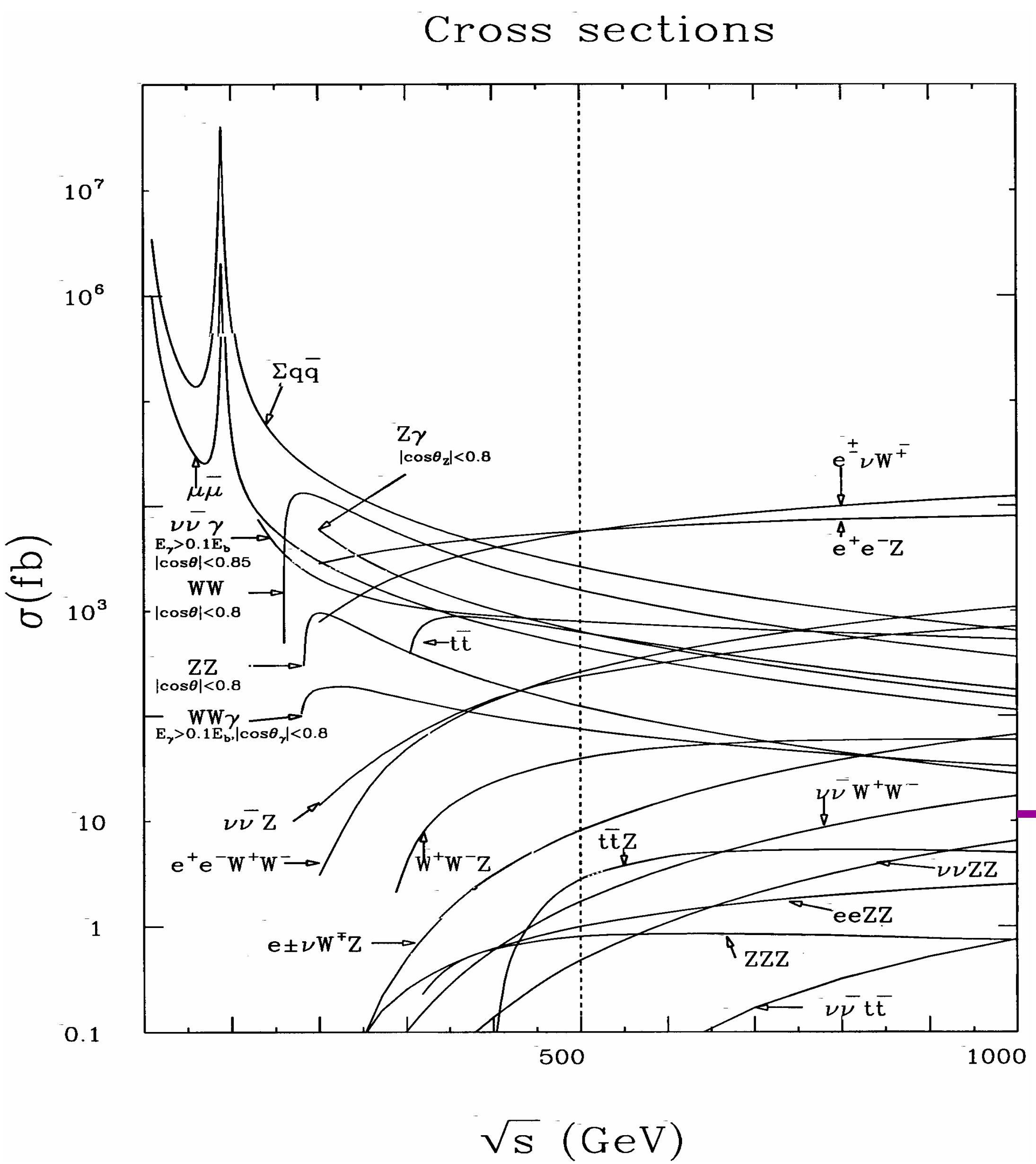
Sources of Muons

- $e^+ + e^- \Rightarrow \mu^+ + \mu^-$
- $e^+ + e^- \Rightarrow \tilde{\mu}^+ + \tilde{\mu}^-$
- $e^+ + e^- \Rightarrow W^+ + W^-$

$\mu + \nu$

Background μ's

z



Linear Collider

$L \sim 1 * 10^{34}\ cm^{-2}s^{-1}$

For one year = 10^7 s

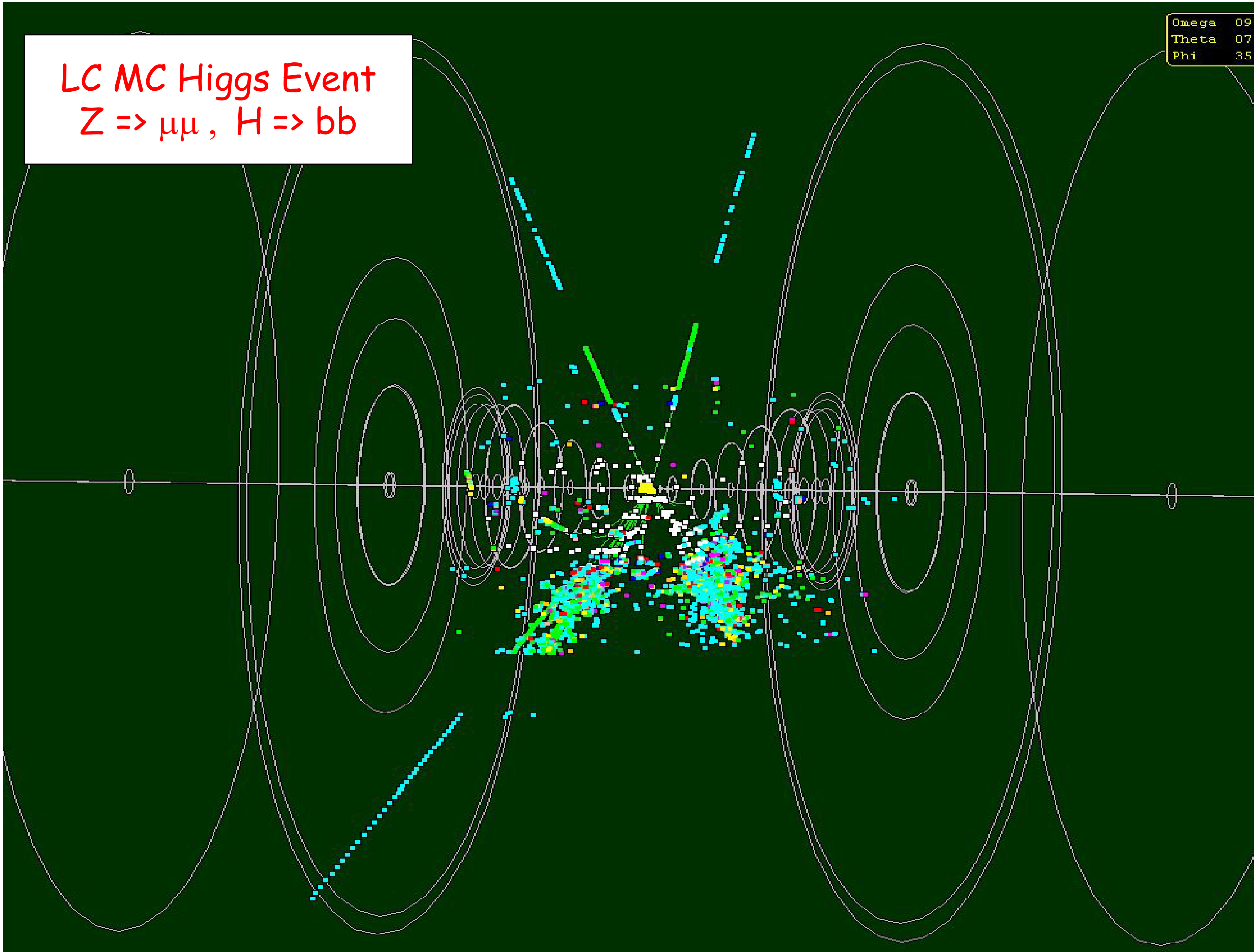
$\int L dt = 10^{41} cm^{-2}$

$= 100\ fb^{-1}$

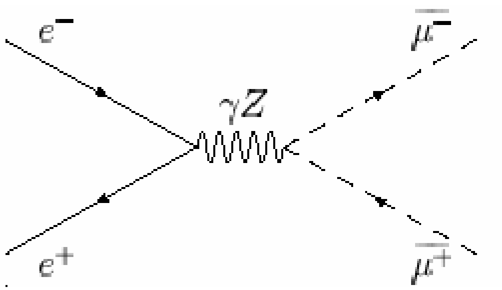
1000 events/yr

LC MC Higgs Event

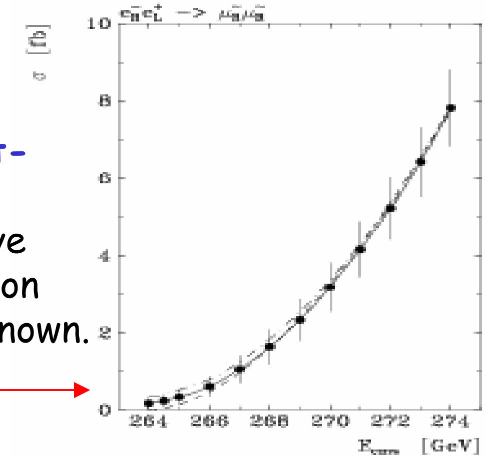
$Z \Rightarrow \mu\mu$, $H \Rightarrow bb$



SUSY: Smuons



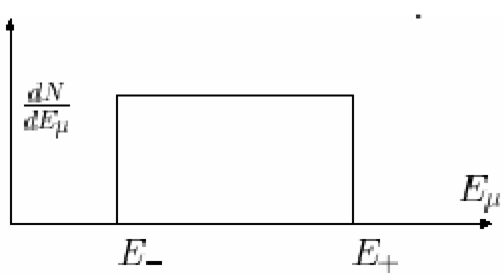
Production of μ_R , partner of the right-handed muon, via $e^+e^- \rightarrow \tilde{\mu}_R^+ \tilde{\mu}_R^-$.
Production of scalar smuon pairs is p-wave which leads to a β^3 threshold cross section that can be measured once the mass is known.



Because the spin of the smuon is 0 its decay to a μ and neutralino χ is isotropic in the rest frame of the smuon and because the smuon's momentum is fixed in the lab, the energy distribution of the μ is uniform with $E\pm$ given by:

$E\pm = (\sqrt{s}/4)\,(1 \pm \beta)\,(1 - m_{\tilde{\mu}}^2/m_\chi^2)$;

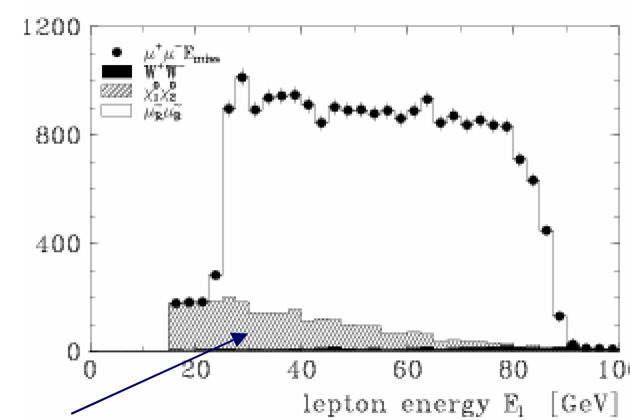
$\beta = (1 - 4m_{\tilde{\mu}}^2/s)^{1/2}$



Such measurements depend on:

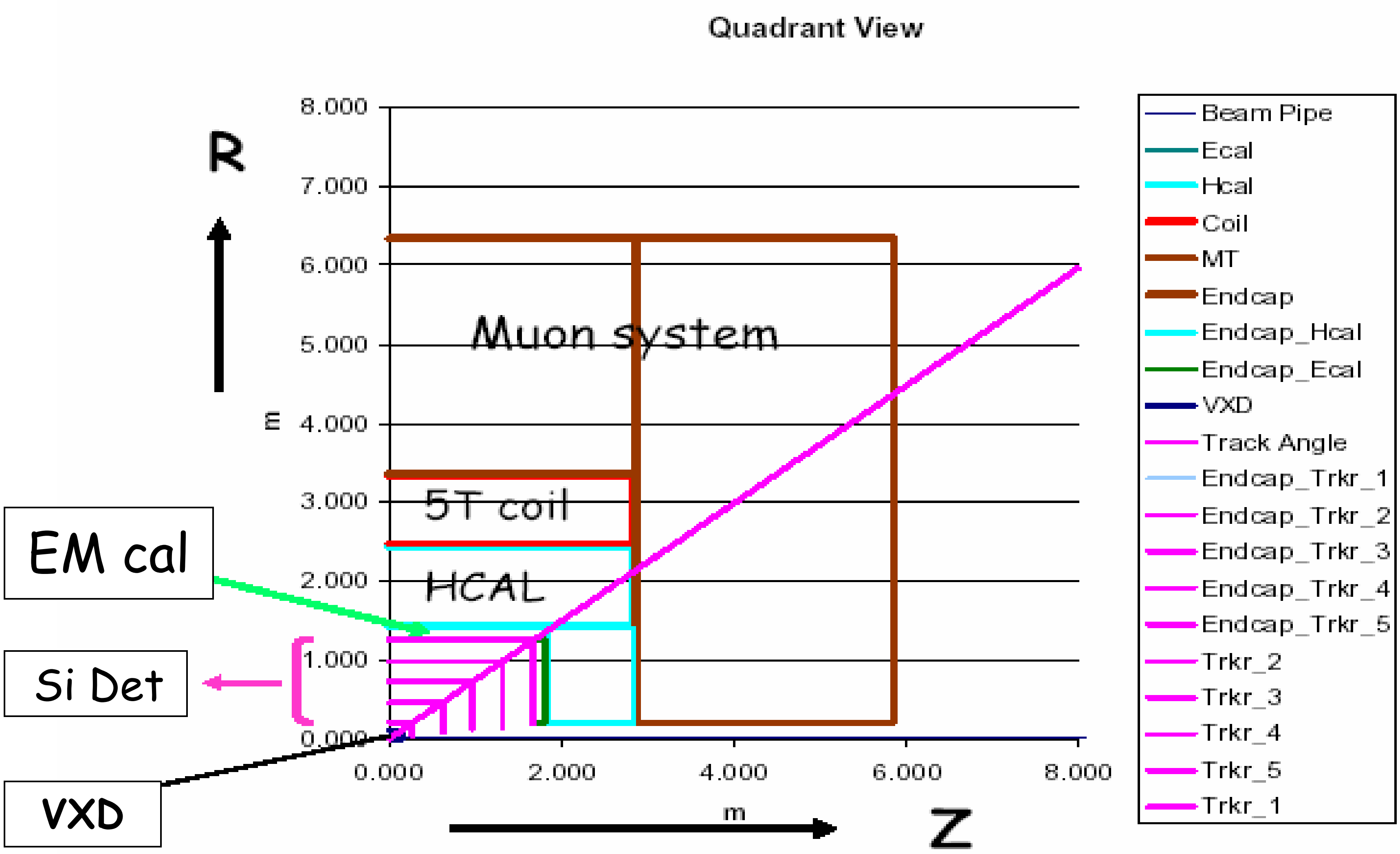
1. Polarization of the e^+ and e^- beams.
2. Clean environment.
3. 4π coverage.

H. Marten, G. Blair hep-ph/9910416



Neutralino bkgd.

SiD LC Detector



Muon Detector Requirements

- Identify muons by their passage through significant amounts of dense material: 10-14 λ. (EM, Hcal & Fe return yoke)
- 10 – 14 hits for good tracking efficiency in the muon detector.
- Link muon candidates found in the muon detector with upstream charged particles.
- Precision P_{μ} done in upstream tracking.
- Muon sys can be calorimeter extension.

μ ID Algorithm Development 1/2004

SiD detector: R_{in} = 349 cm;
R_{out} = 660 cm.
5 cm thick Fe; 32/48 1.5 cm gaps instrumented.

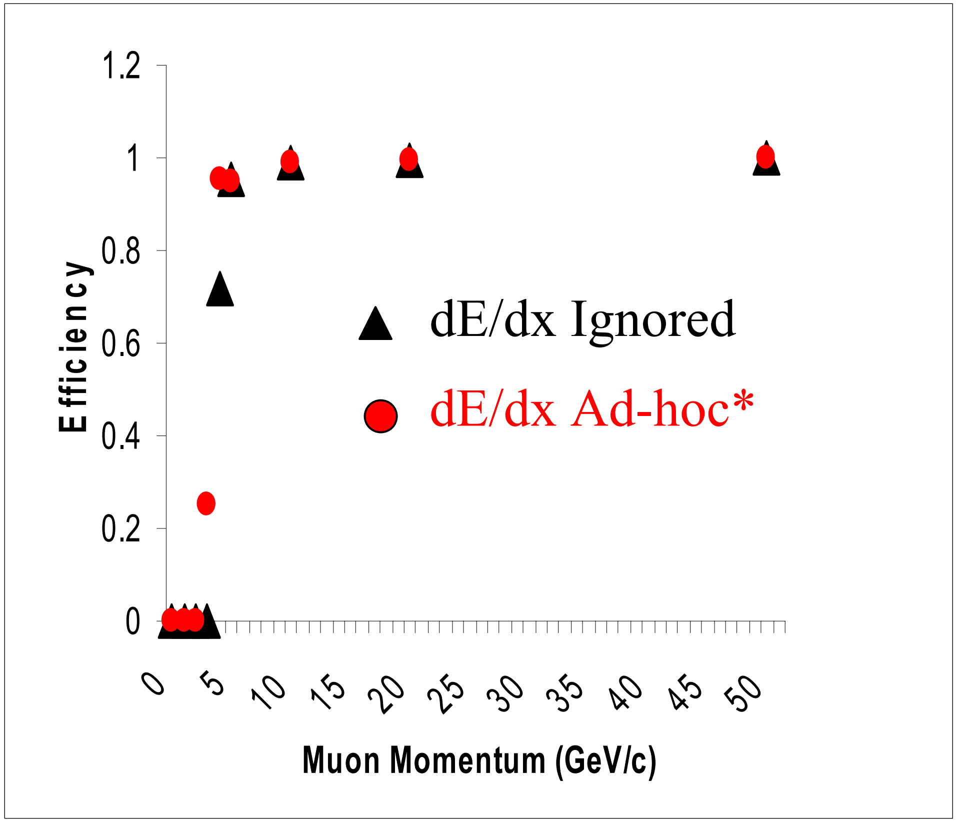
1. Extrapolate fitted tracks to EMCal, HCal and MuDet.

2. Collect hits in ($\Delta\theta$, $\Delta\varphi$) bins about extrapolated trks.

3. For muons with p $\geq$ 3 GeV/c requires 16hits in $\geq$ 12 out of 32 layers taking into account an Ad-Hoc dE/dx (* Hit collection within an angle varying ~1/p).

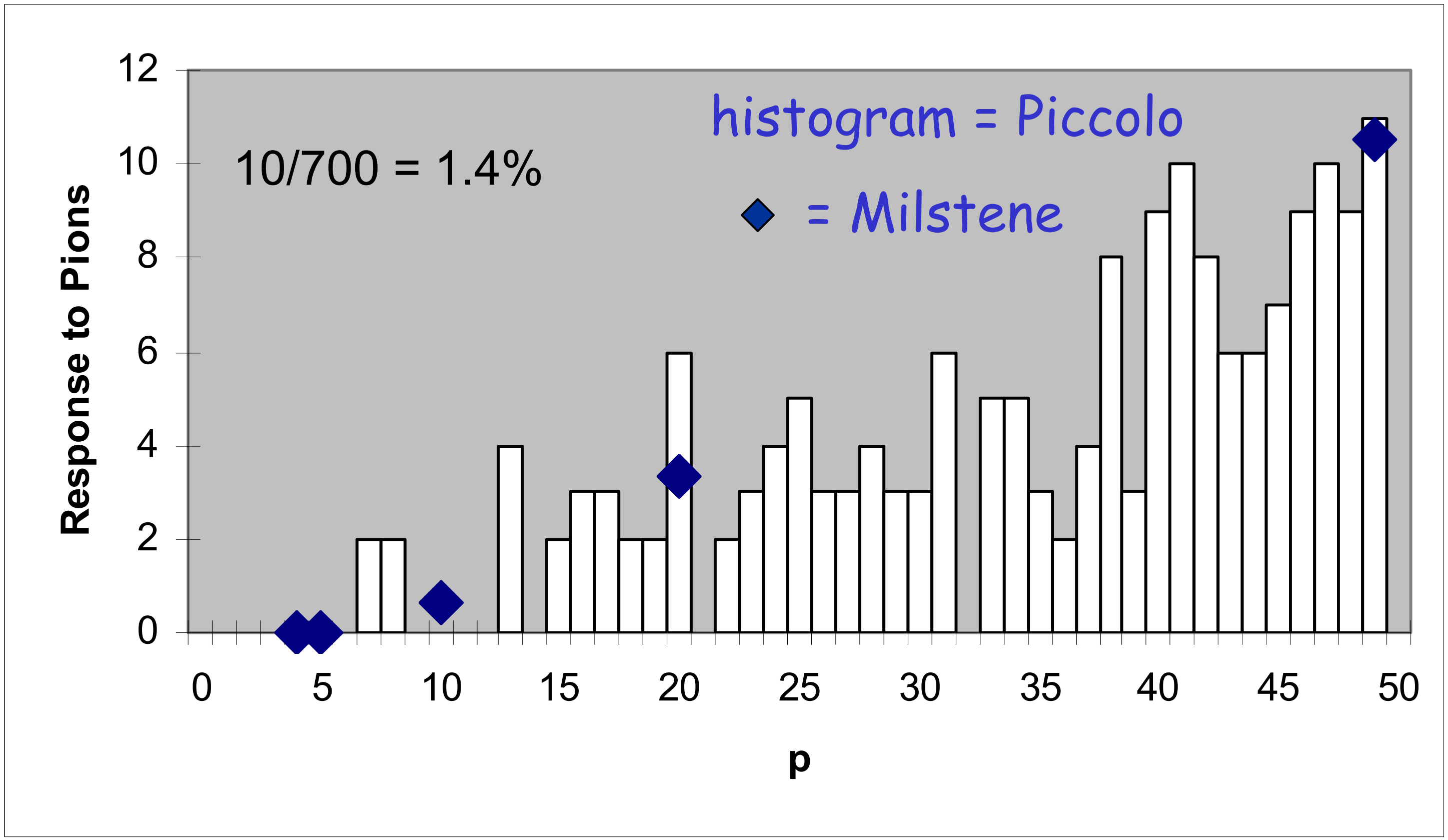
Similar TESLA studies by M. Piccolo

Single Muons with the Swimmer



μ ID Algorithm Development

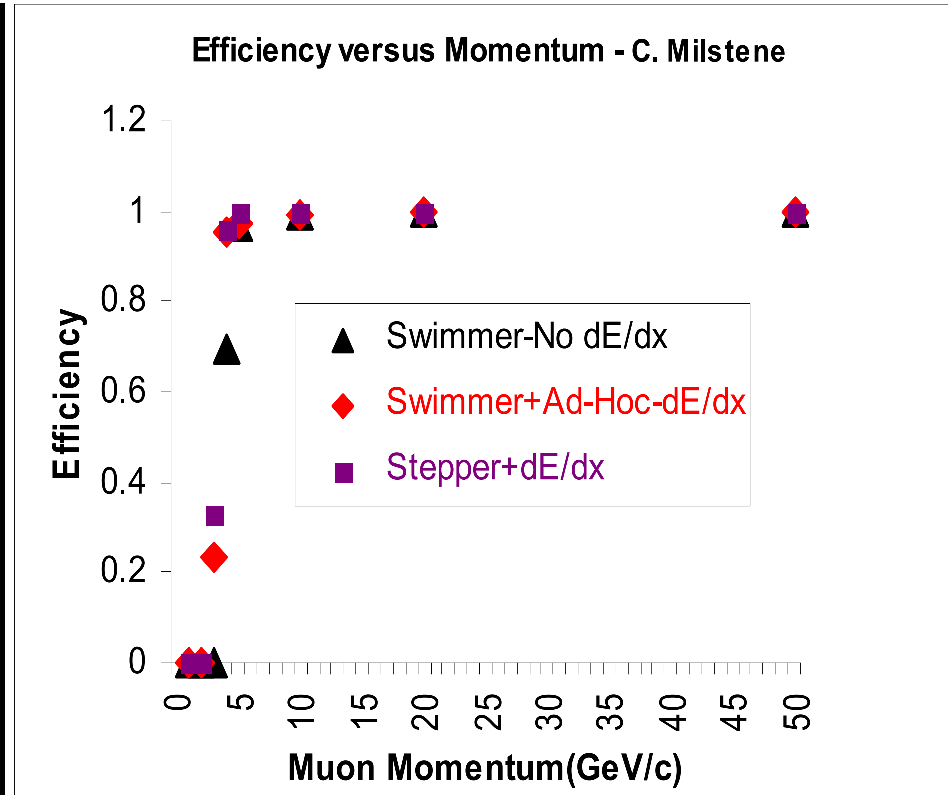
Analyze single pions with the same algorithm to get punch-through. At 50 GeV/c it is 1.4%.



Stepper Results - Single Muons

C. Milstene

E(GeV) \ Techn.	3	4	5	10
No dE/dx	0.06%	70%	97%	99.%
Ad-Hoc dE/dx	23%	95%	97%	99.%
V x B + dE/dx	33%	96%	99%	100%

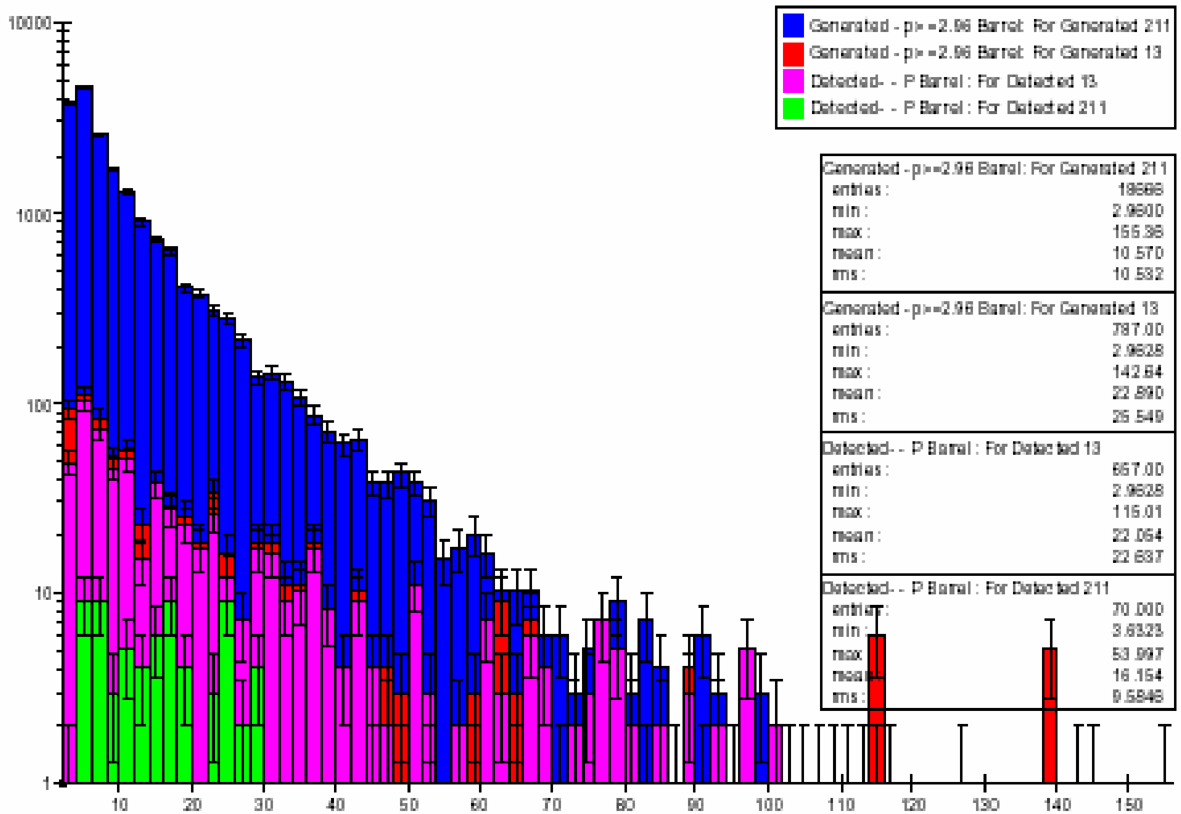


Low energy muons may be very important!

Punchthrough Studies with b-$\bar{b}$ Events

10k b-bbar-Pions & Muons Generated With P>2.96 GeV

C. Milstene



P(GeV/c)- 2GeV/bin

- Generated Pions in Blue
- Generated Muons in Red
- Detected Muons in Magenta

- Pions Detected as Muons In Red

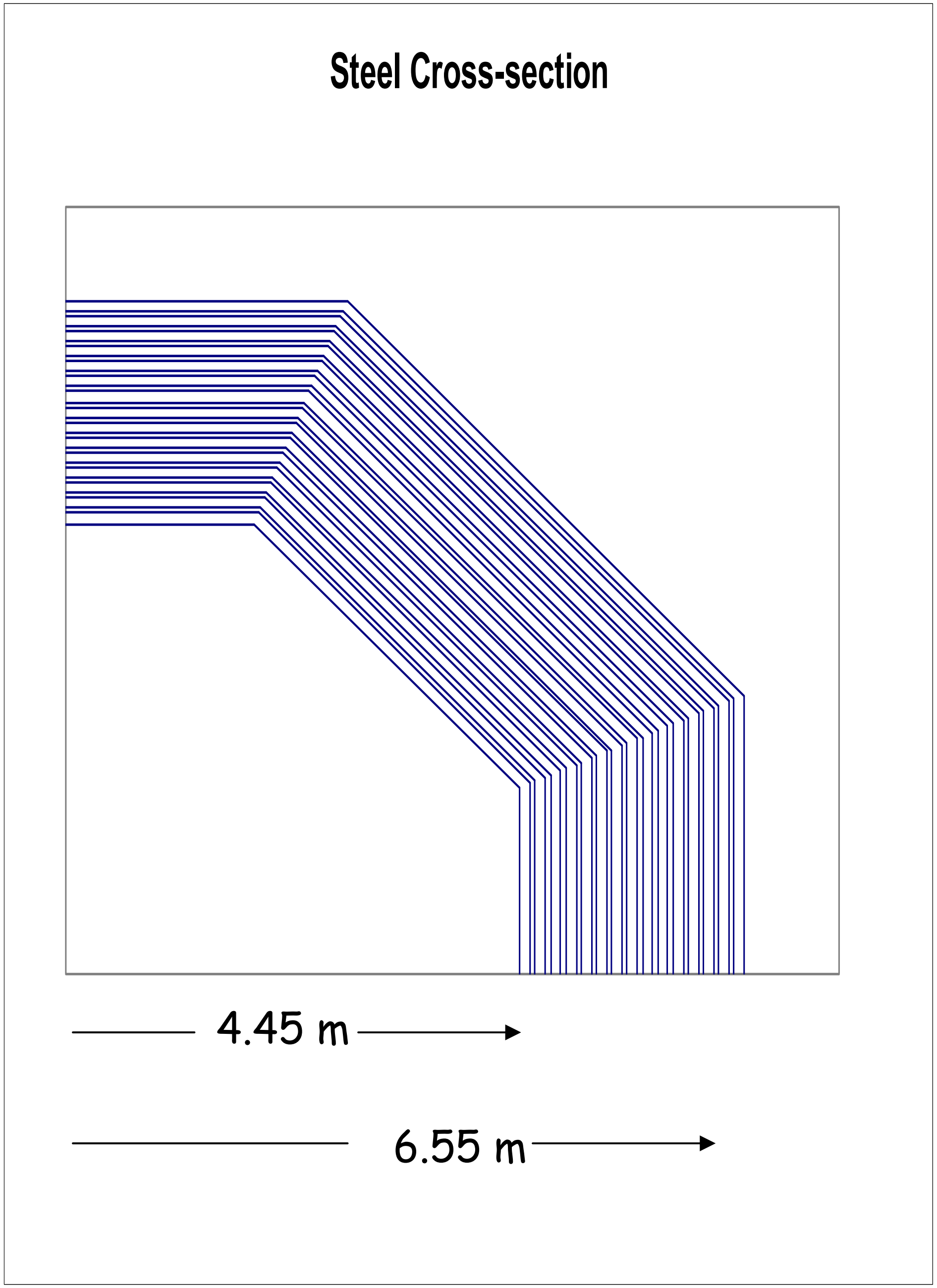
Remark:

Below 2.96 GeV the Particles do not reach The Muon Detector

Steel Cross-section

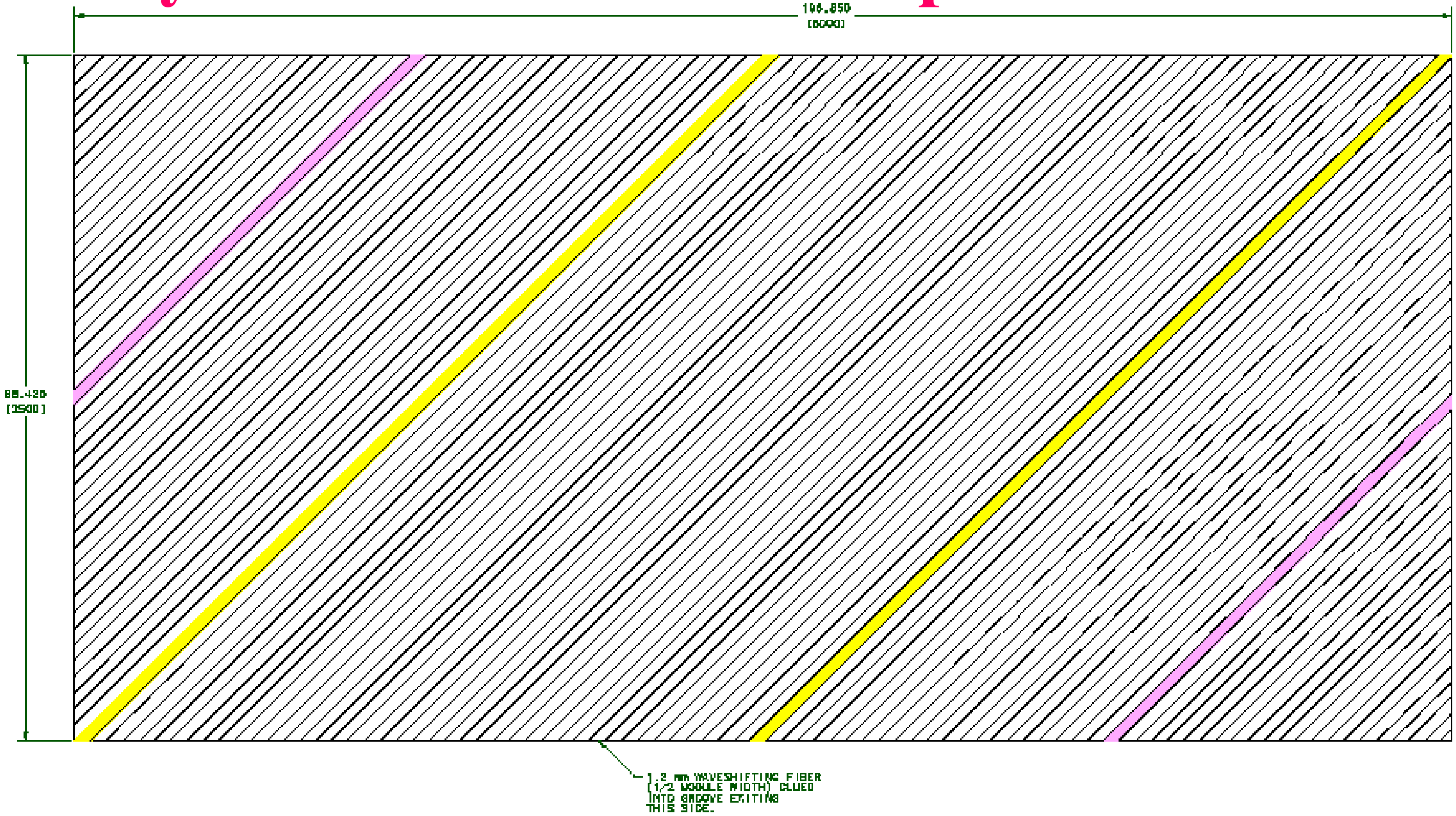
Fe thickness = 10 cm,

Gaps = 5 cm



Hardware Development

Layout of Scintillator Strips in one Plane



Multi-Anode Photomultiplier Tube Tests, Calibration and Front-End

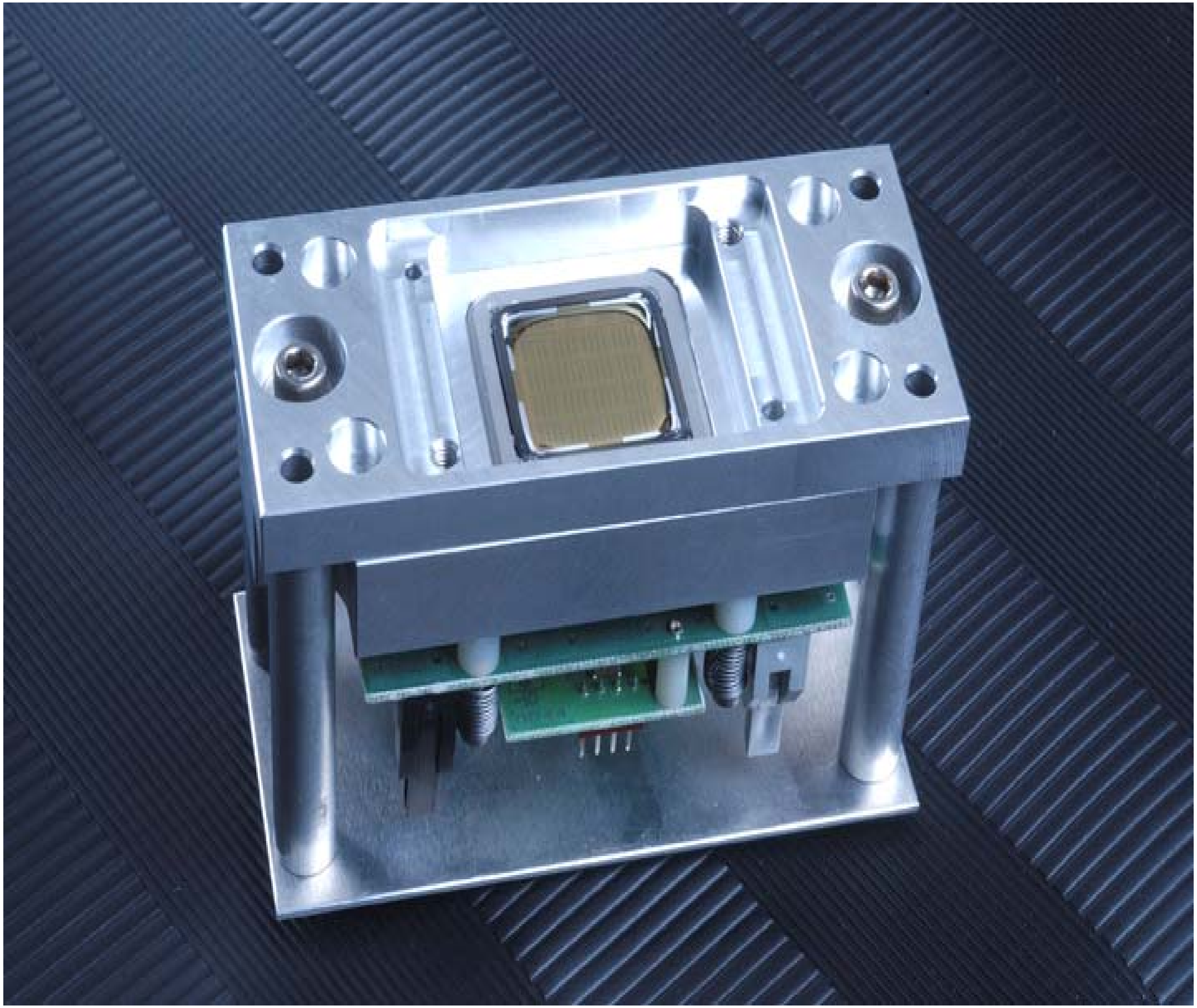
Scintillator Based Muon System R&D for a Linear Collider

Paul Karchin
Wayne State University
Department of Physics and Astronomy

Personnel:

- Paul Karchin, Physicist
- Alfredo Gutierrez, Research Engineer
- Marcel Leonard, Undergraduate Physics Student (Fall 2003)
- Rajesh Medipalli, Physics Graduate Student (Summer 2003)

MINOS base NIM HV supply - Bertan 375 X



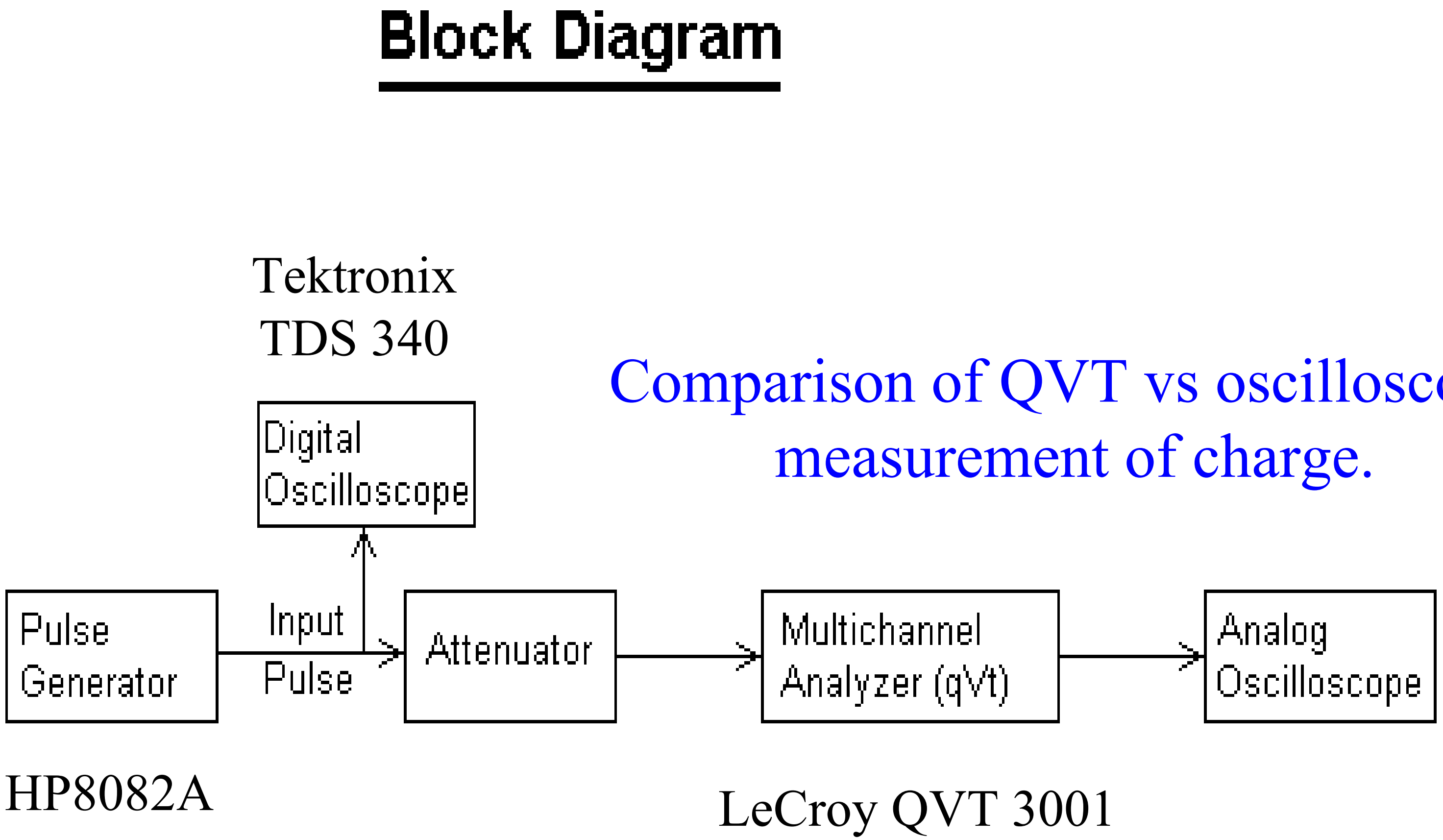
Paul Karchin April 2004

Stability and In-Situ Calibration of a Large Scale System

Test set-up generated with an LED pulser, etc to:

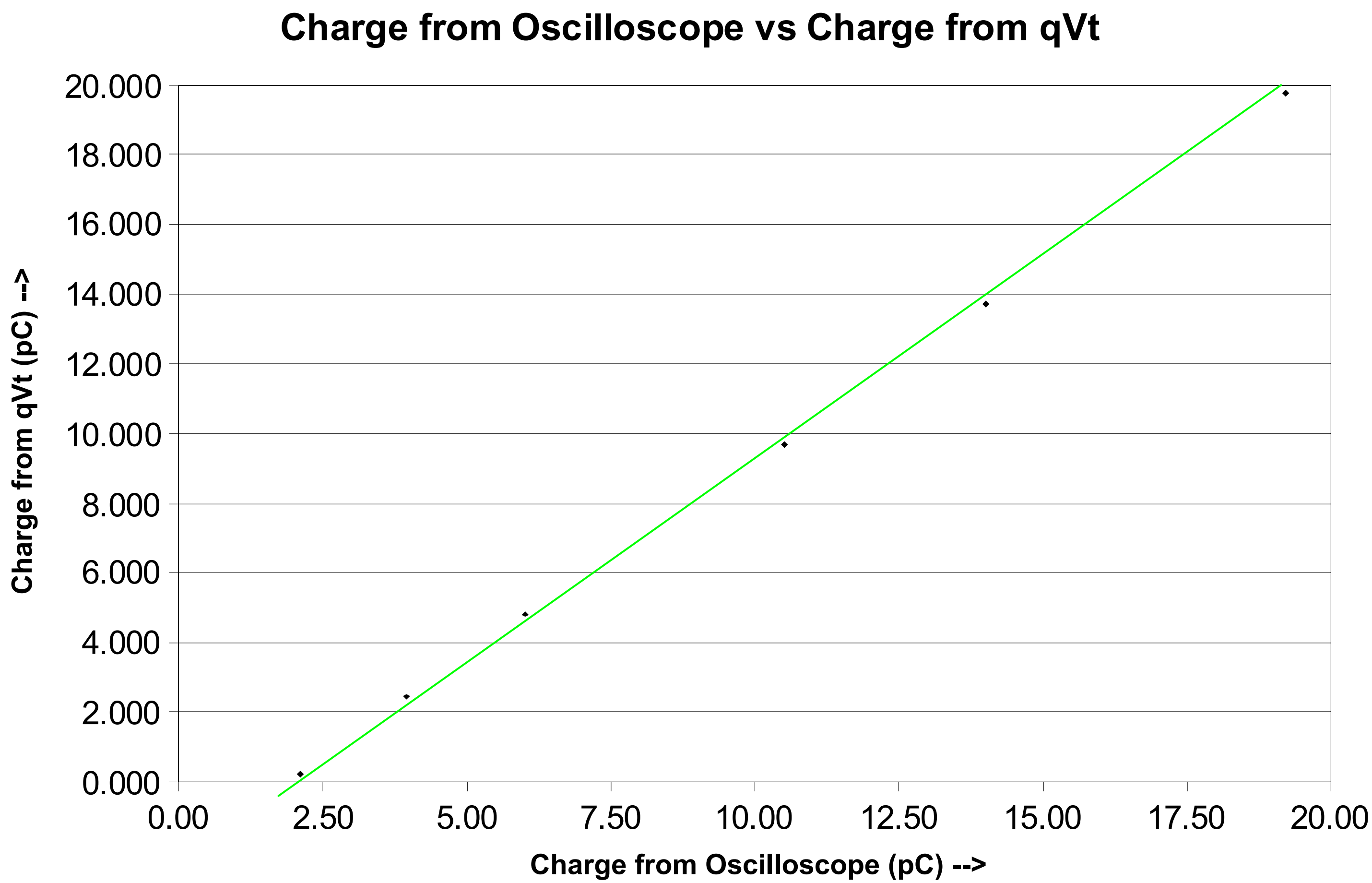
- Establish linearity of pulse height analysis system;
- Measure the properties of MAPMTs.
- Investigate potential use of LEDs for detector calibration.
- Eventually compare with other methods of calibration:
  - Cosmic rays
  - Radioactive sources

Charge calibration system for pmt anode pulses



Comparison of QVT vs oscilloscope measurement of charge.

Paul Karchin April 2004

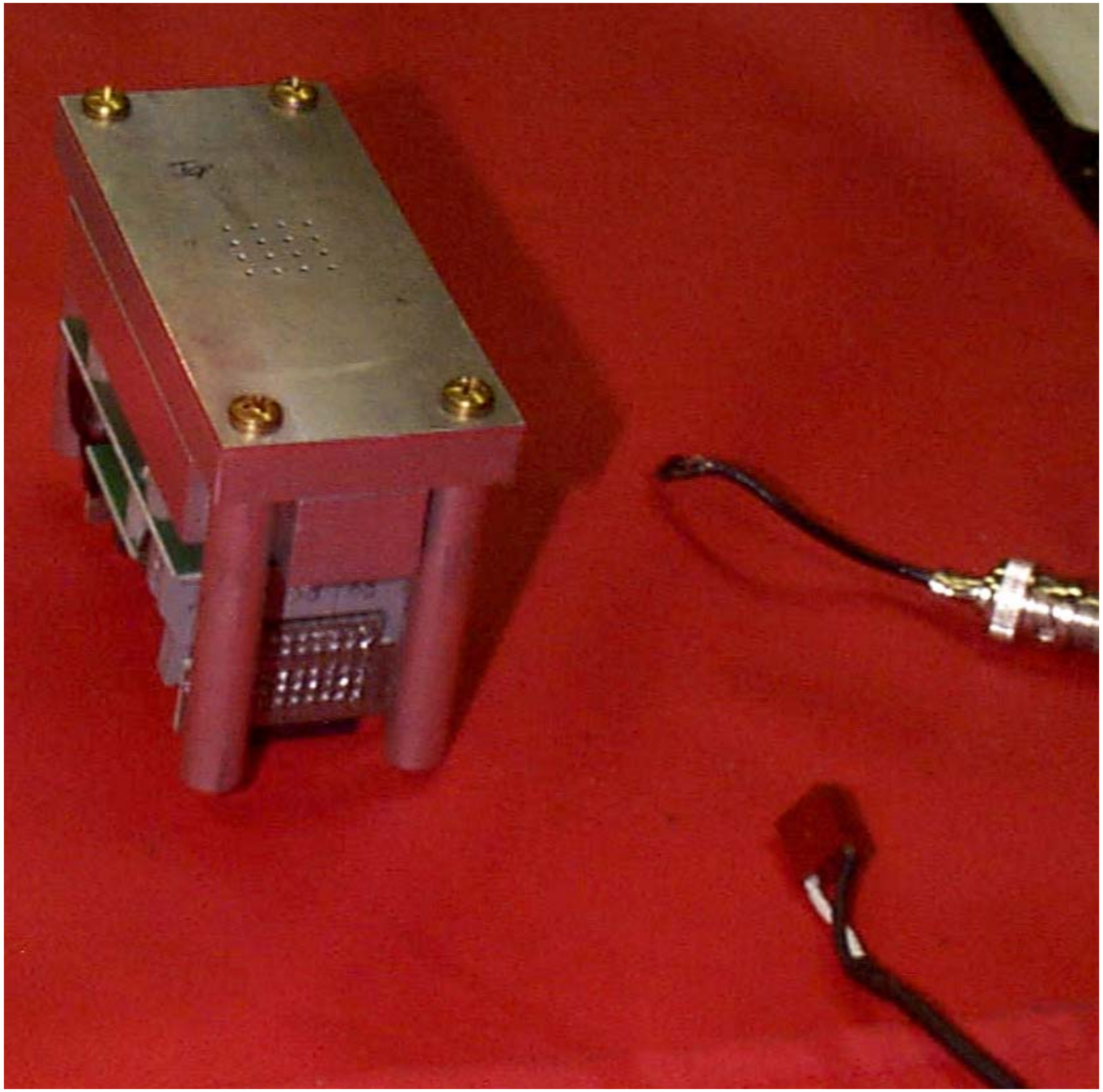


To prepare for precise measurement of the charge in MAPMT pulses, a Lecroy QVT 3001 was calibrated with a pulse generator and a Tektronix TDS 340 digital oscilloscope. A charge of 1 pC is the expected response from the MAPMT for a single photoelectron and MAPMT gain of 6 X 10^6. The calibration curve is linear with a significant pedestal offset of about 2 pC.

Paul Karchin April 2004

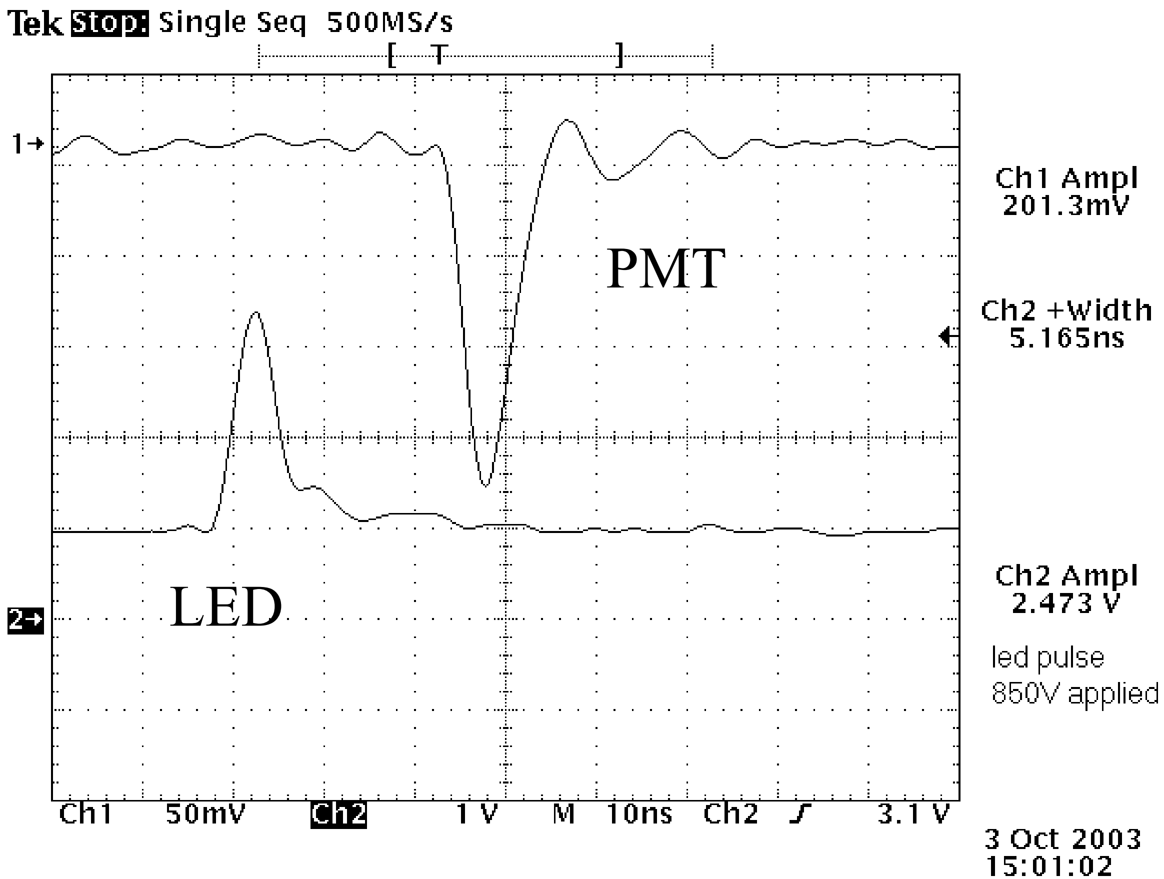
Light Injection and PMT Readout

A Hamamatsu R5900-M16 MAPMT mounted in a MINOS (far detector) base. The assembly has been modified to accommodate an aluminum guide for optical fibers. The 16 holes in the aluminum block are aligned With the MAPMT photocathode grid. Ambient light or pulses from an LED are injected into individual pixels. Cables are visible for HV bias and anode signal readout.



Paul Karchin April 2004

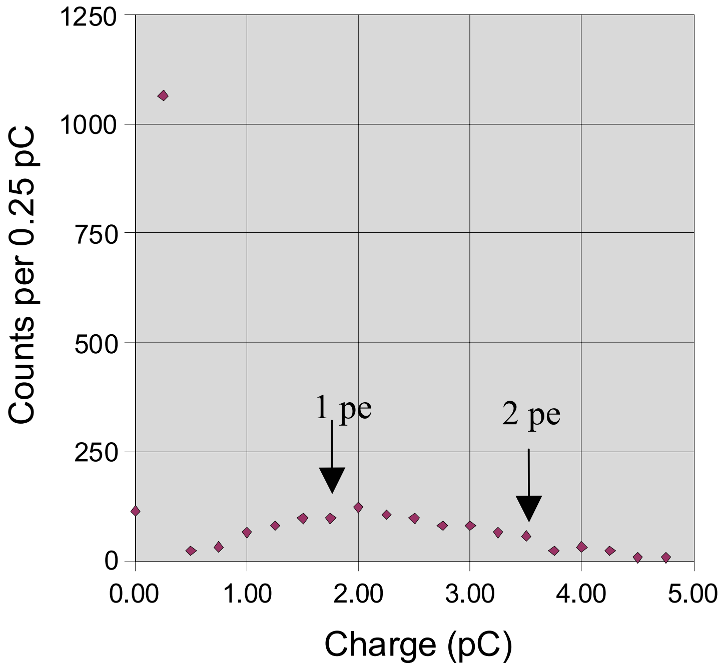
M16 PMT with MINOS base – response to LED pulse



Paul Karchin April 2004

Measurement of single channel charge distribution in response to low light level LED pulses

MINOS MAPMT Channel 15 at 950 V



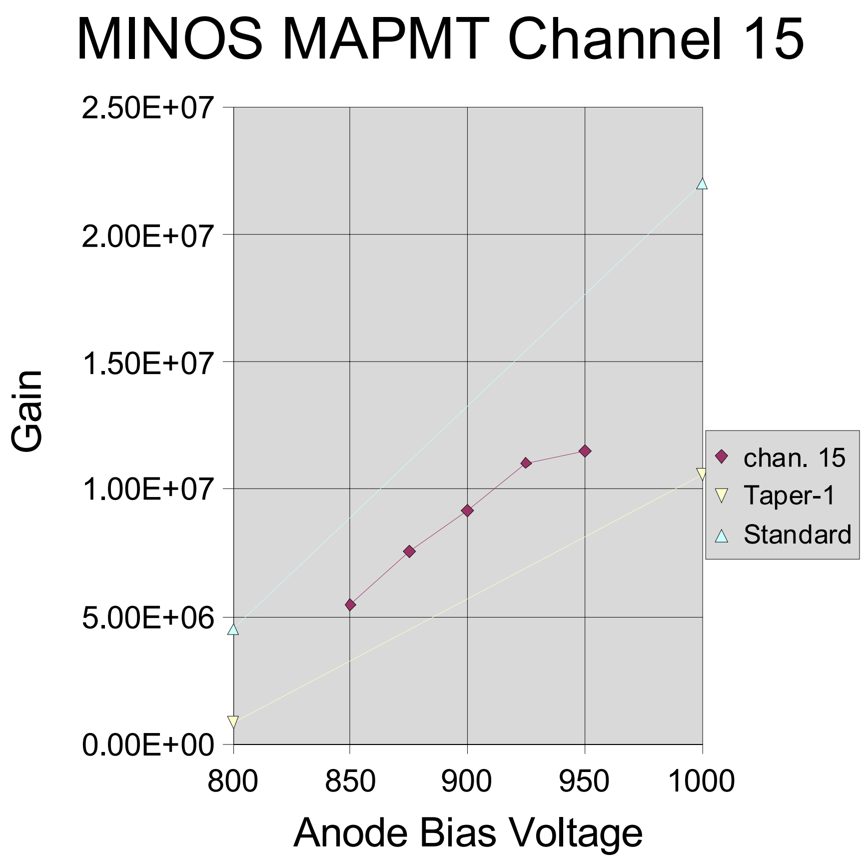
Prob(0) = sum(pedestal)/sum(ped+signal)

$$\langle N_{pe} \rangle = -\ln \mathrm{Prob}(0) = 0.66$$

$$\langle Q \rangle = 1.23 \text{ pC}$$

$$\text{PMT Gain} = \frac{\langle Q \rangle}{\langle N_{pe} \rangle\, e} = 1.15 \times 10^{7}$$

Measured gain versus anode bias voltage for a single MAPMT channel and comparison to R5900-00-M16 reference data



Optical Fiber Work at Notre Dame

Personnel: Mitch Wayne (physicist), Mike McKenna (technician)
Mark Vigneault (technician), Tom Burger (undergraduate student)

Fiber Splicing

Motivation

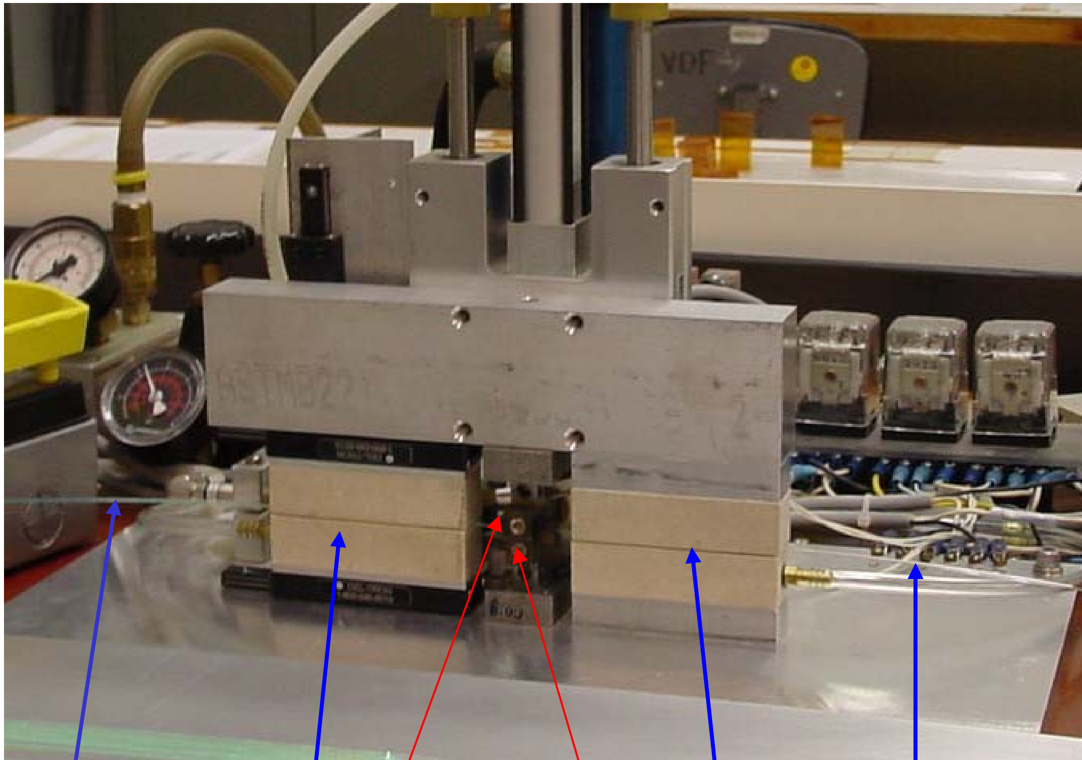
– Splicing the waveshifting fiber to the clear readout fiber provides a secure, space efficient connection. The need for connectors is eliminated and the overall design of the muon detector is simplified.

Drawbacks

– Splicing is "manpower intensive".

– Splice is permanent, can't be repaired once it is installed.

Thermal Fiber Splicer



WLS Fiber
1mm dia.

Fiber – Vacuum Clamps

Dual Heating
Blocks

Clear Fiber

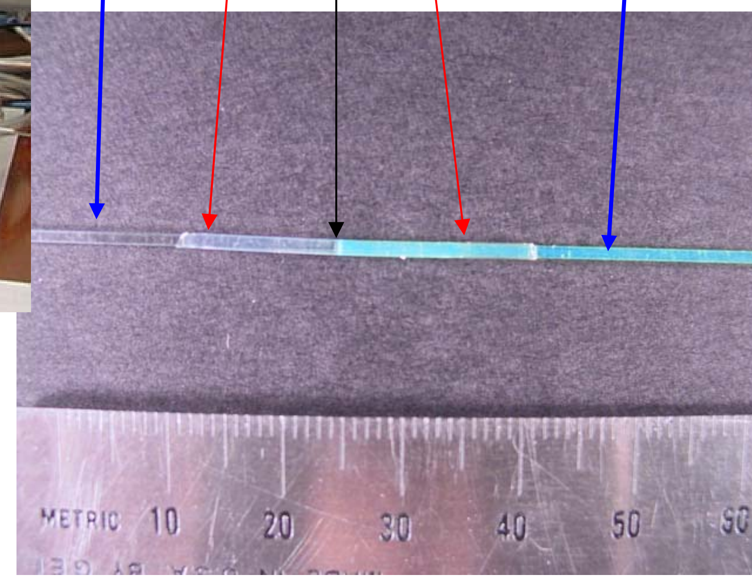
Sample Splice

Clear Fiber
1 mm

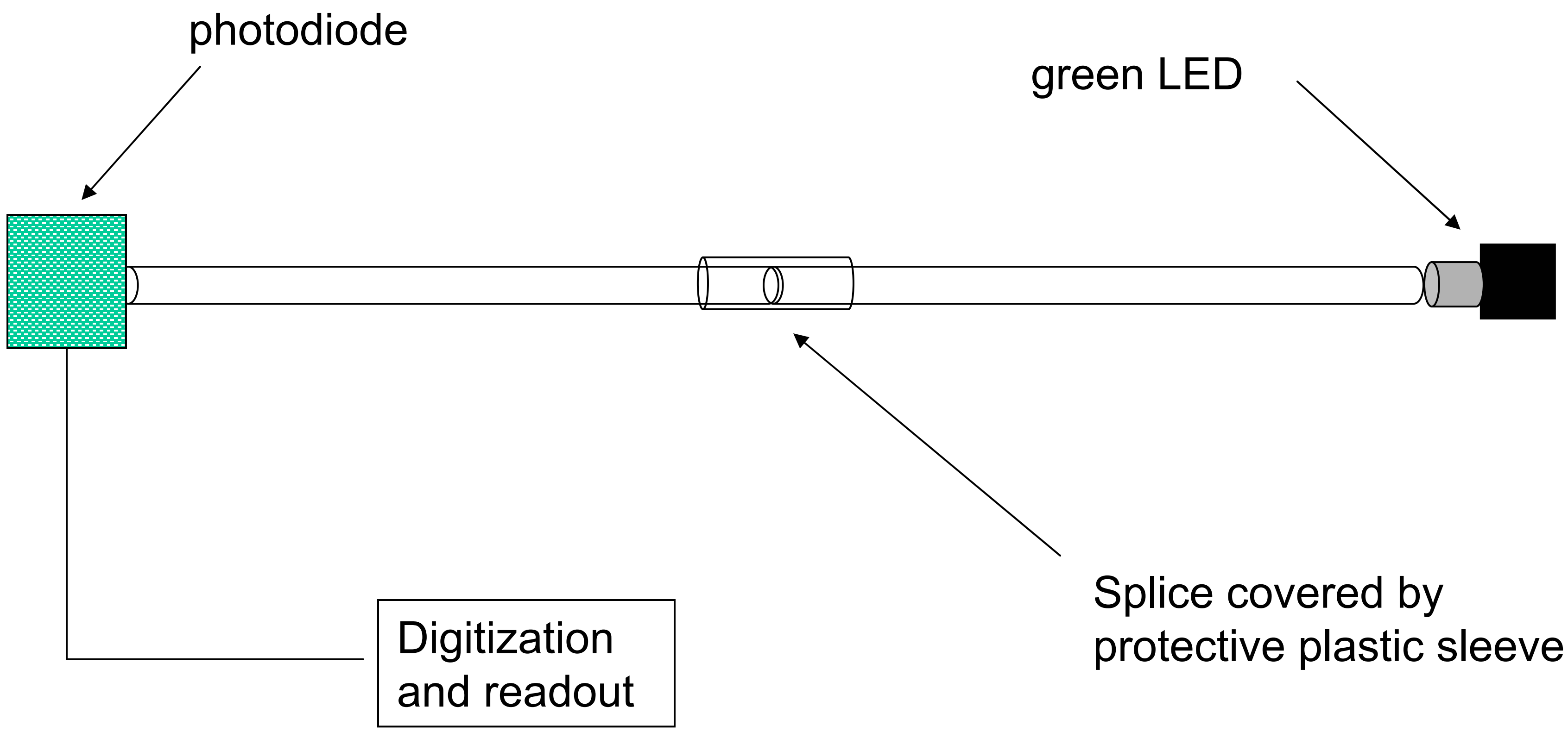
WLS
Fiber

Teflon sleeve

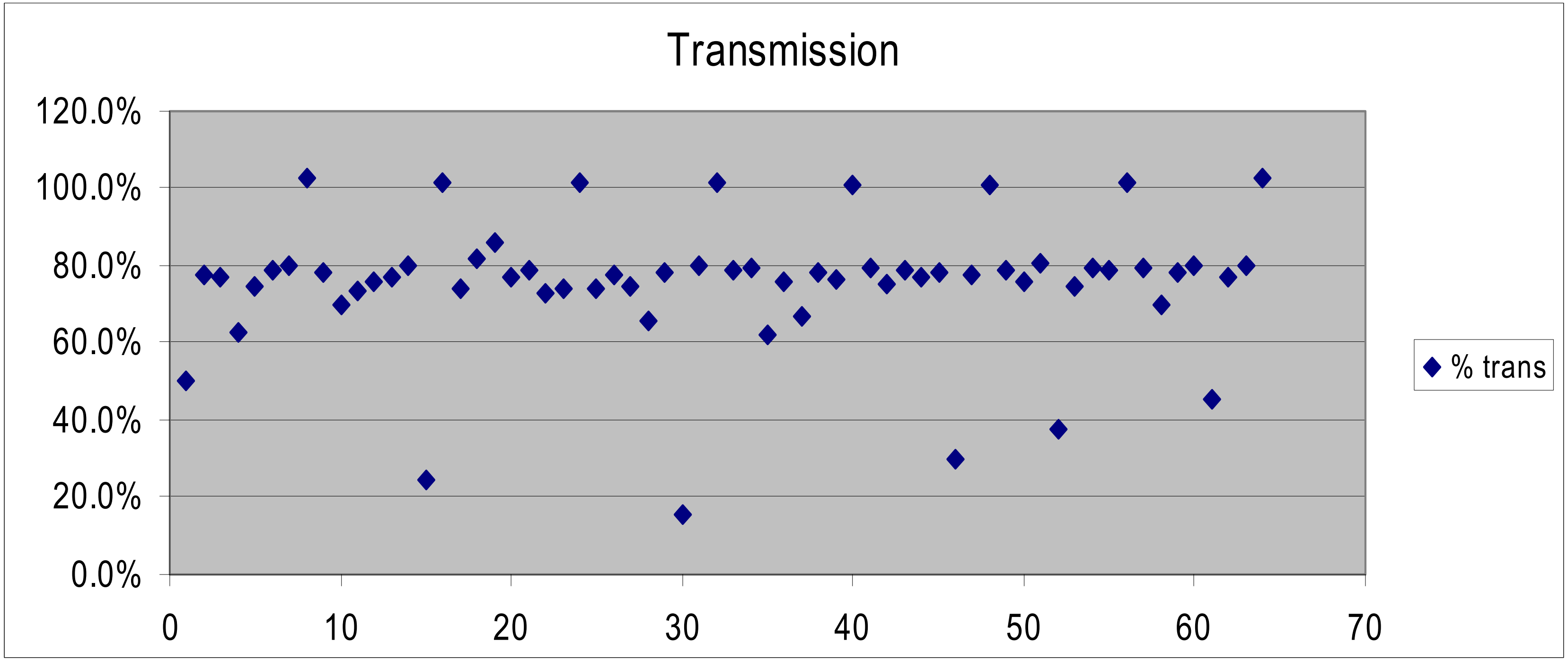
Joint



Apparatus

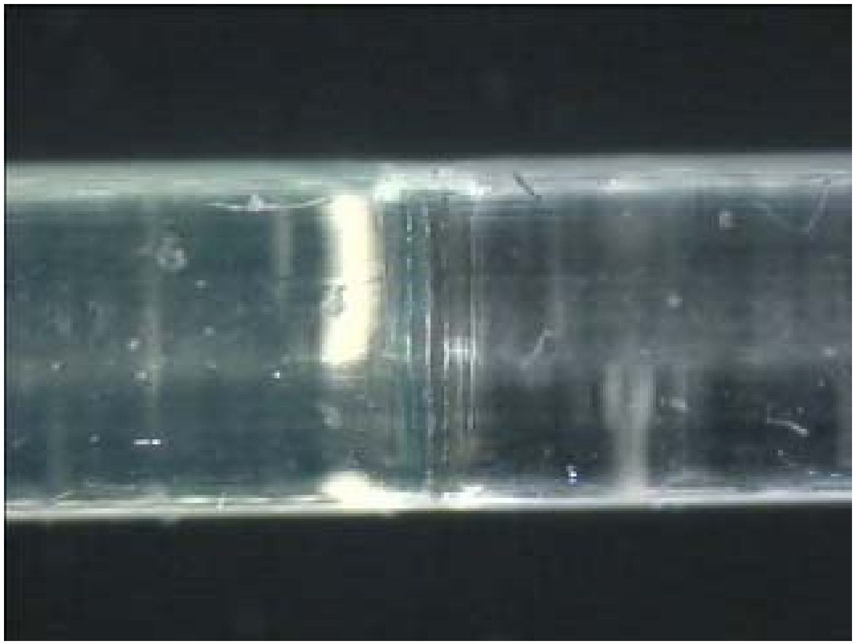

photodiode
green LED
Splice covered by protective plastic sleeve
Digitization and readout

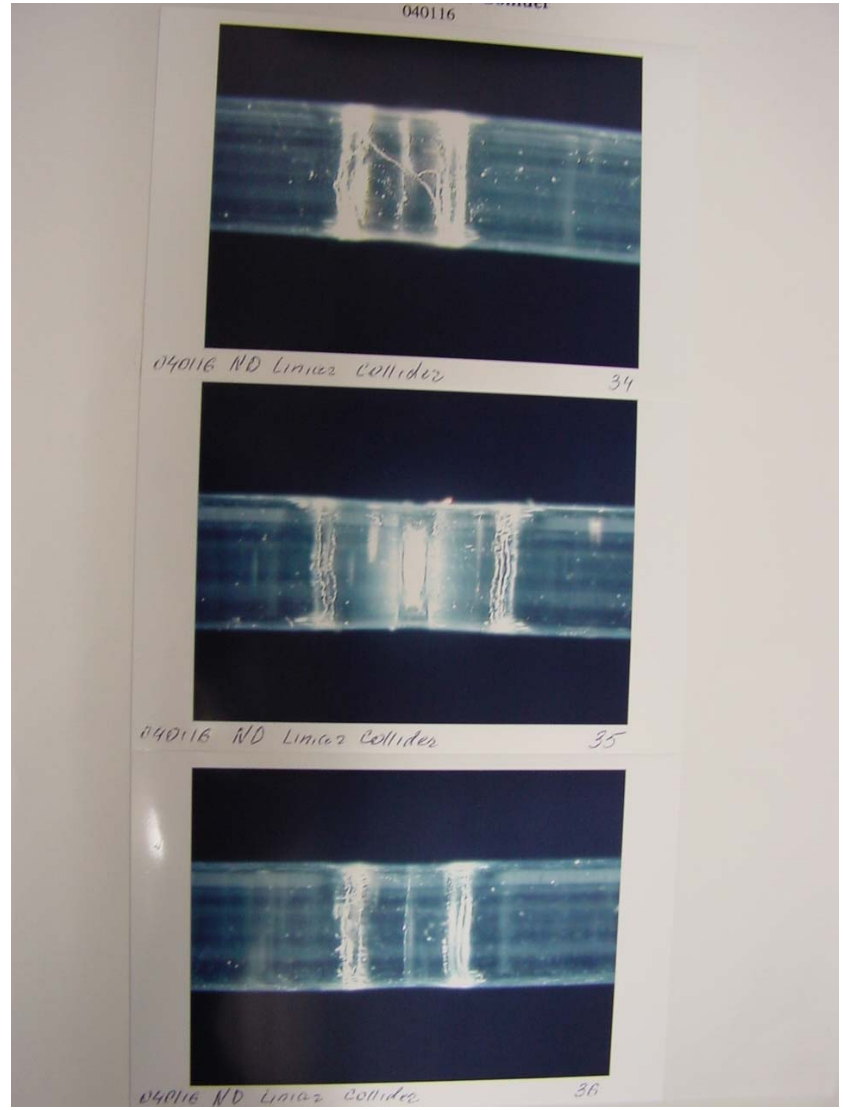
Results



- Several splices with very poor transmission (losses > 50%)
- Typical transmission of ~75 - 80%
- Control fibers w/100% transmission show system stability.

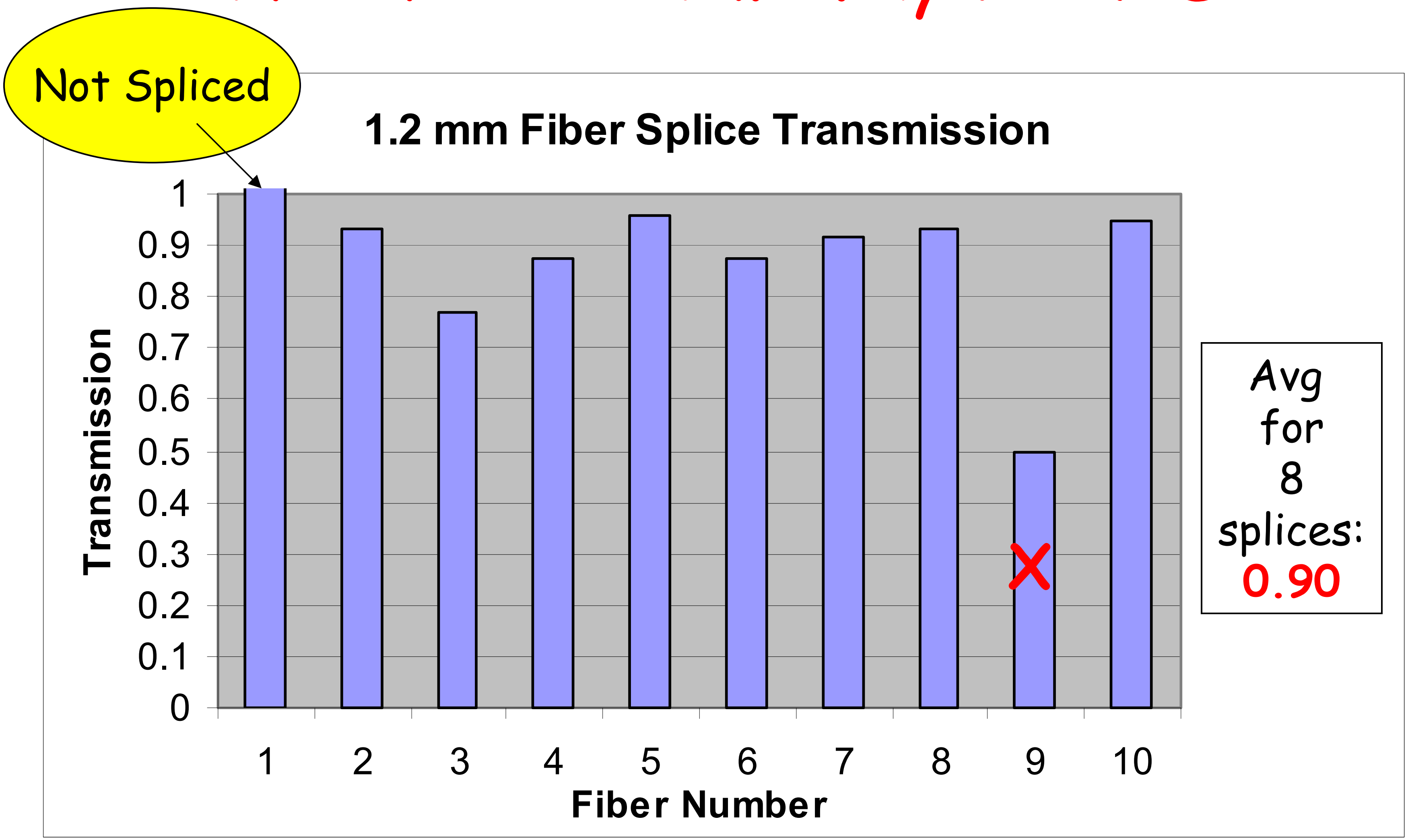
Fiber Splice Pictures





Eileen Hahn April 2004

Straightened Fiber Splice Tests 7/28/2004 M. Wayne UND

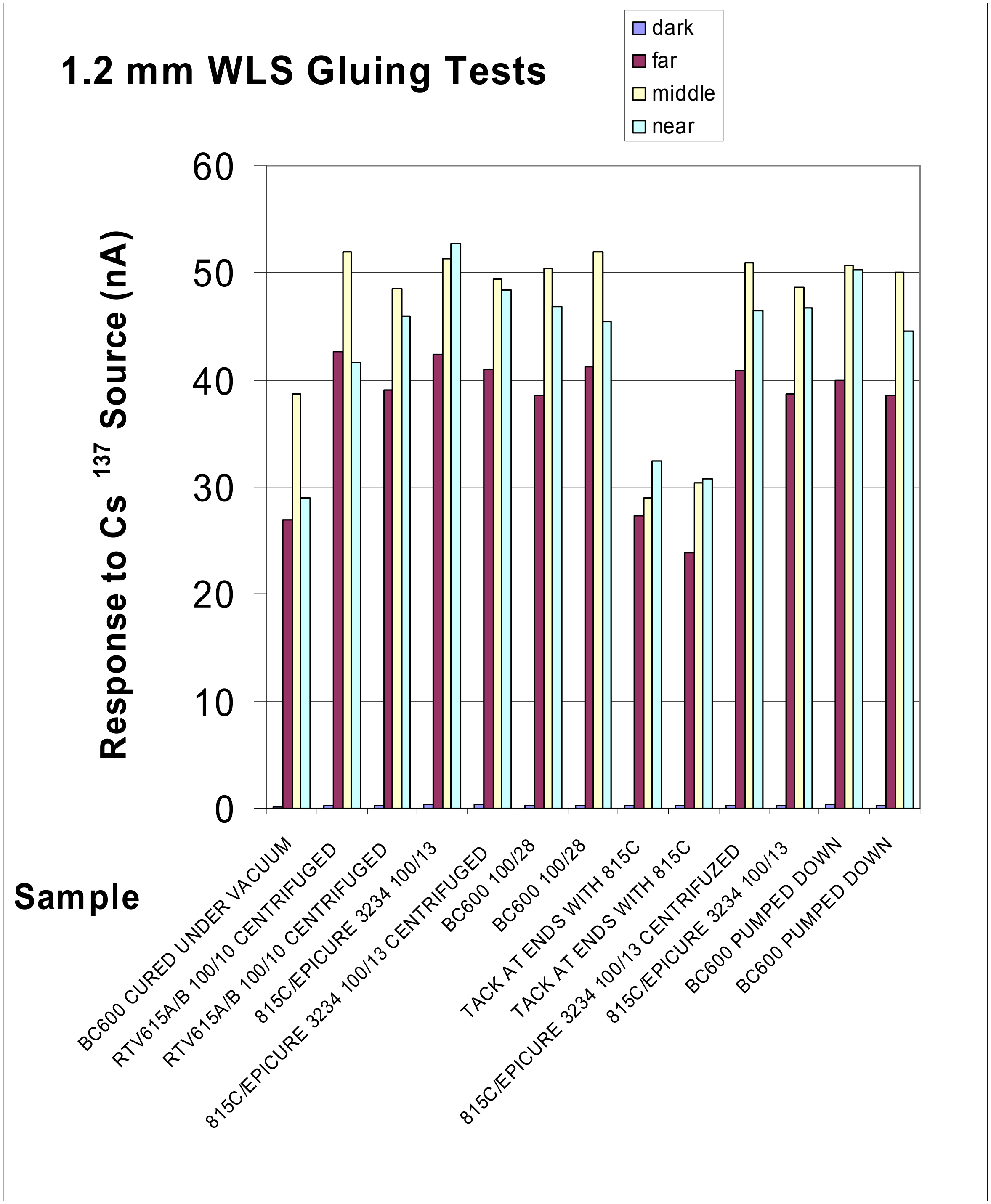


1m long scintillator gluing and light yield tests

Sasha Dychkant's Measurements of Strip Response using a Cs^{137} source.

May 19, 2004

~ 15 p.e.s

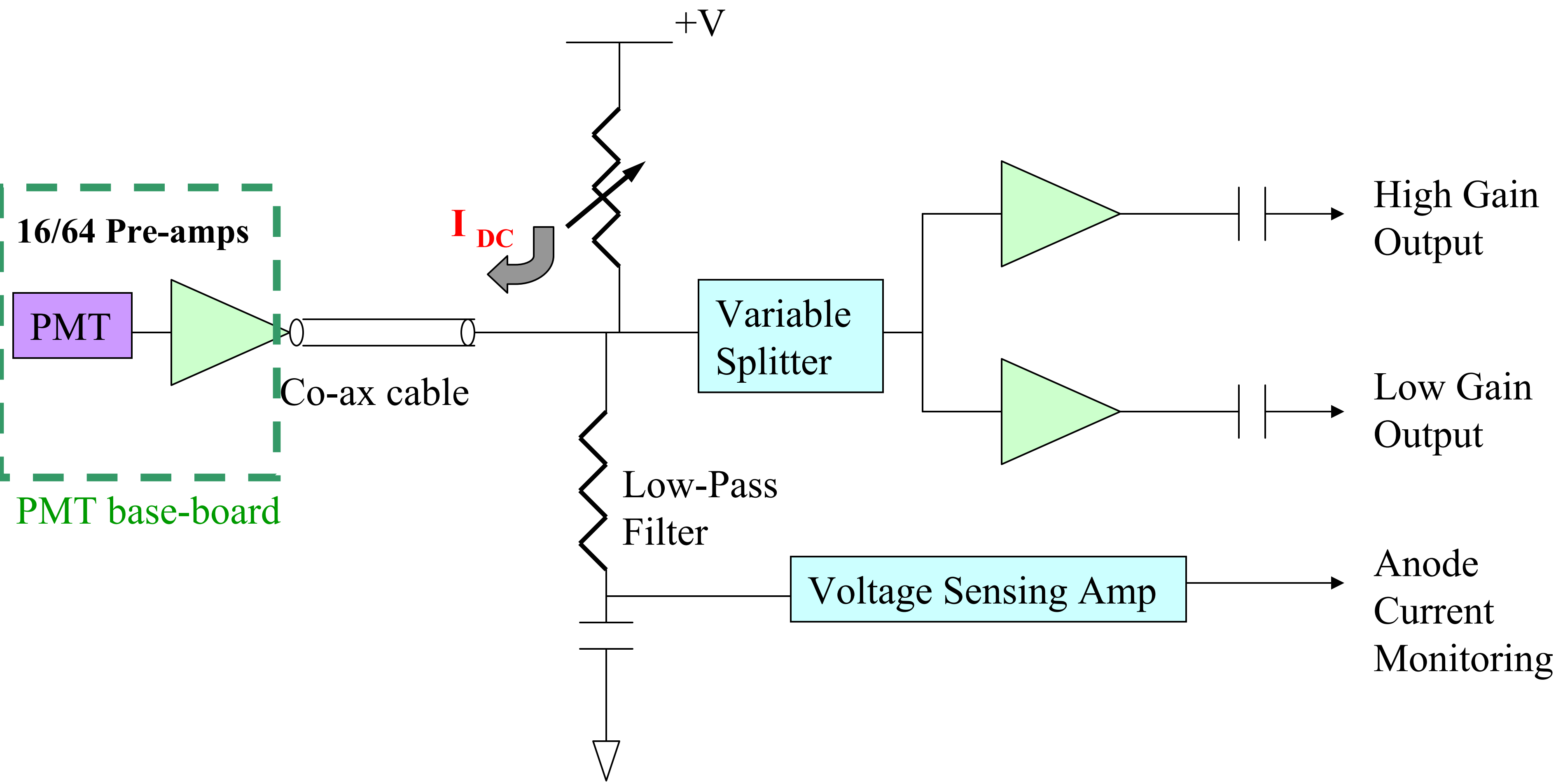


Readout Electronics for the LC Muon Detector Prototype

Mani Tripathi
Britt Holbrook (Engineer)
Juan Lizarazo (Grad student)
Cherie Williams (Undergrad student)
University of California, Davis

Linear Collider Workshop
Victoria
07/29/2004

Front-end Electronics: System Schematic



- The Pre-amp is powered by I_{DC} from the Amp which also measures the anode current.
- The co-ax cable is expected to be ~100’ long, with minimal signal loss.

MAPMT test-stand

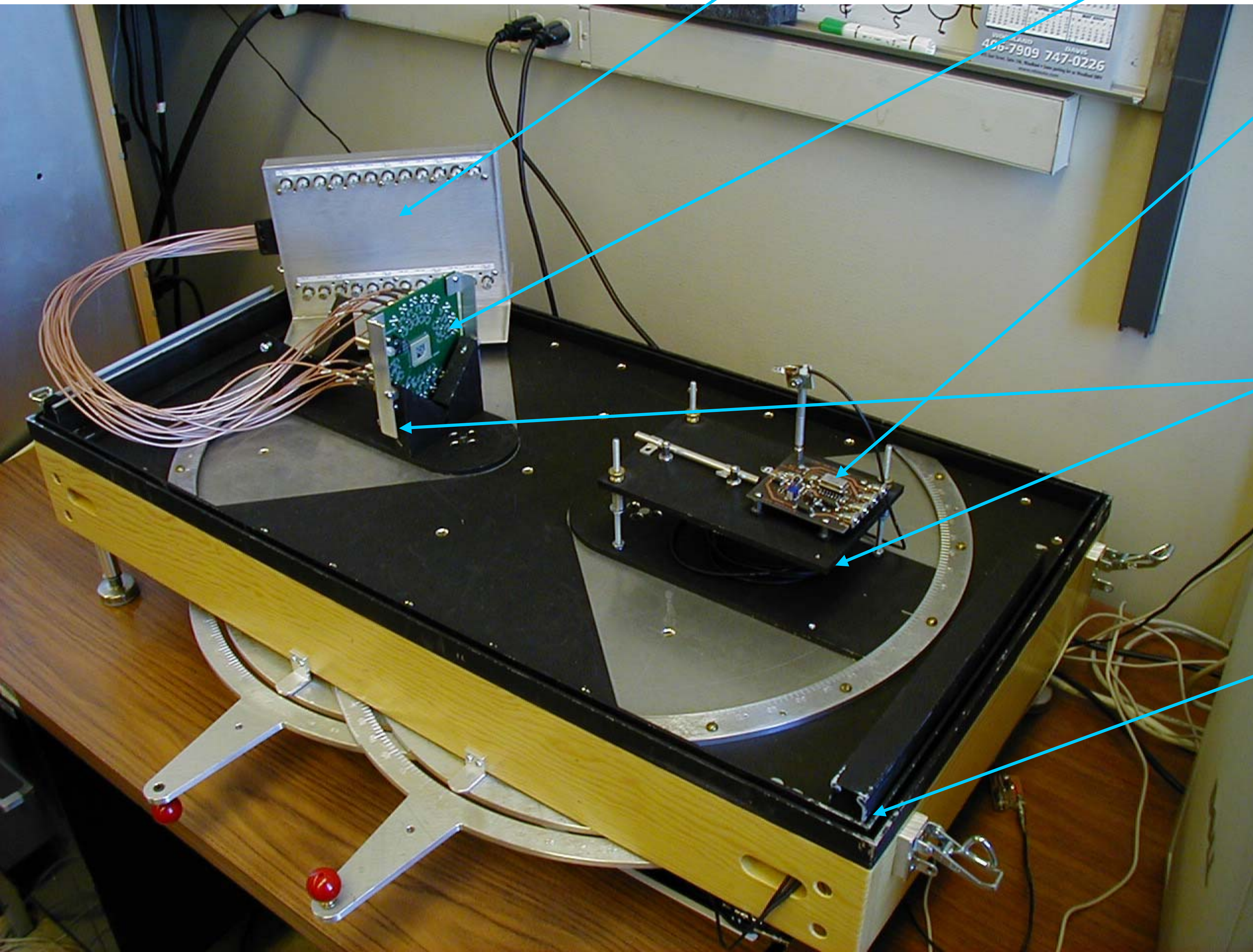
Bias-board

PMT/Pre-amp Board

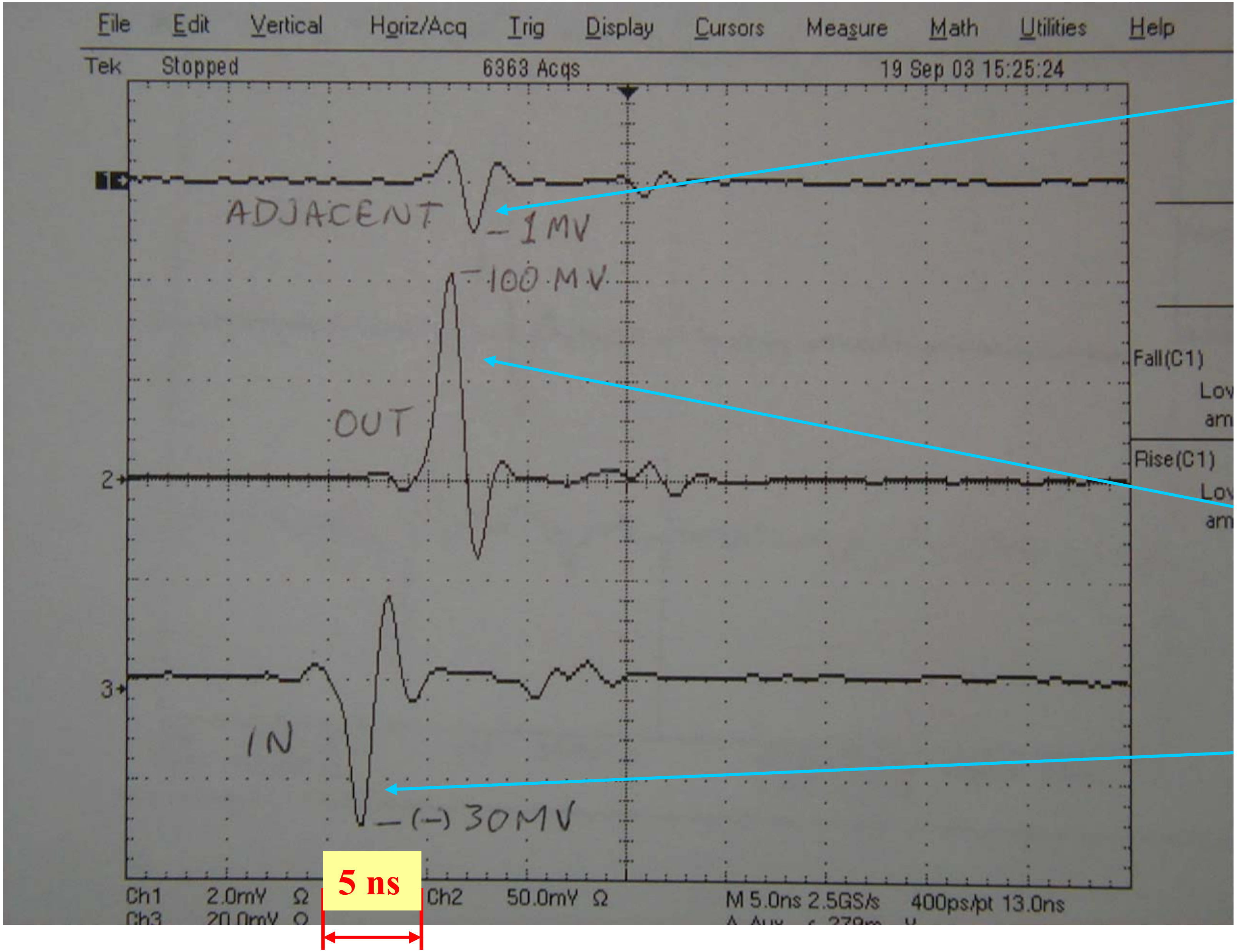
LED Pulser

Mounts With 90^{o} Calibrated Rotation

Dark-box



Response of the Amplifier to a test-pulse



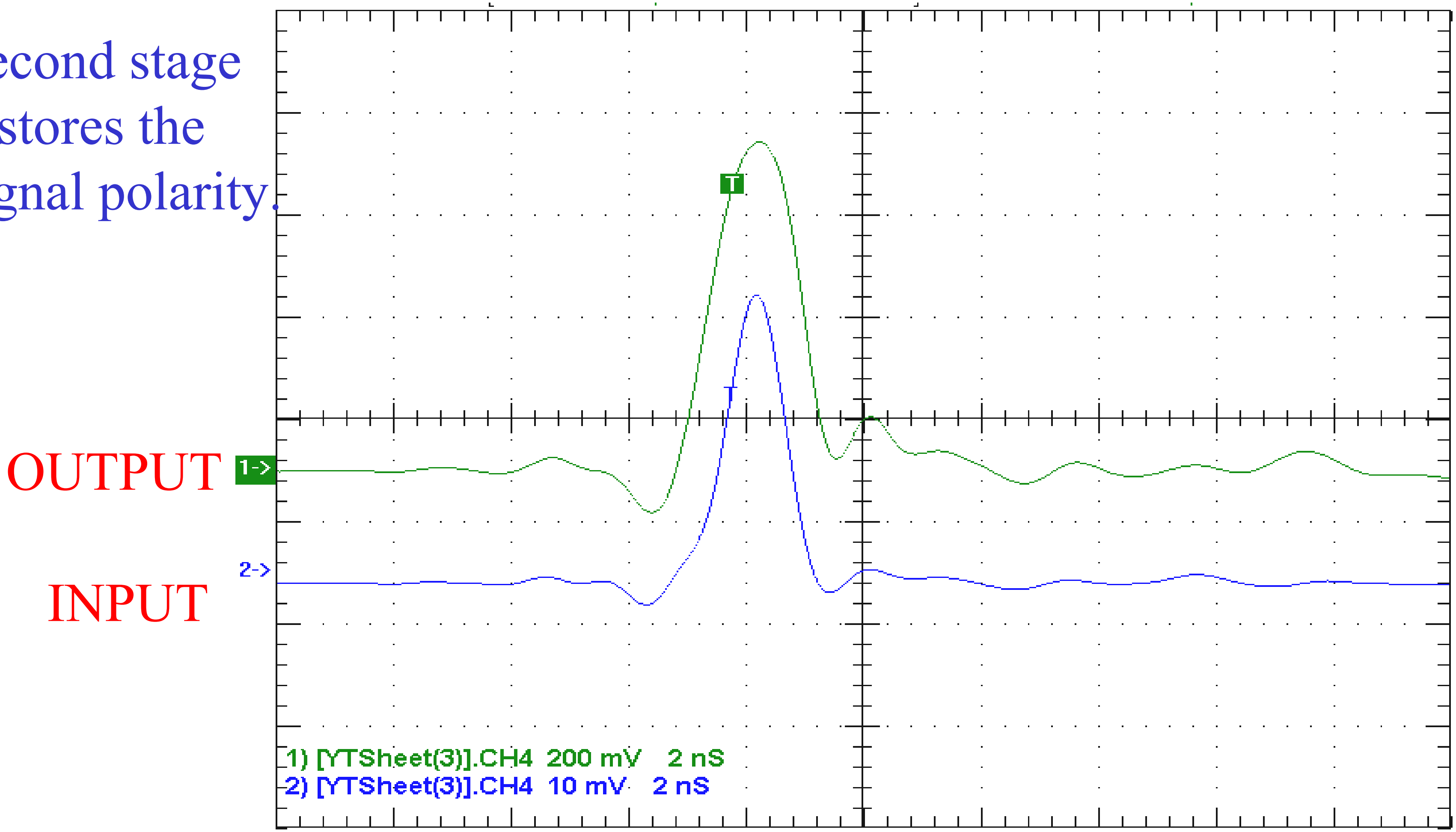
Output in Next channel (x-talk)

Output (gain~3)

Input

Post-Amplifier Response

Second stage restores the signal polarity.



The amplifier reproduces the input pulse shape faithfully
=> the inherent rise-time of the amplifier is better than 1 ns.

Issues for the Readout Design

Time-of-arrival determination

Time of Arrival (TOA) measurement is desirable for correct bunch crossing assignment.

Decay time (~6-8 ns) in WLS fiber is expected to dominate timing jitter. Faster fibers are expected in the future.

The electronics should be able to record TOA to <1 ns in order to not add further error.

For exotic weakly interacting heavy particles, we will need to measure time-of-flight.

For the prototype system it is best achieved by utilizing CAMAC TDCs (LRS3377) available at Fermilab. These modules provide 0.5 ns resolution with *O*(8 ns) two pulse separation.

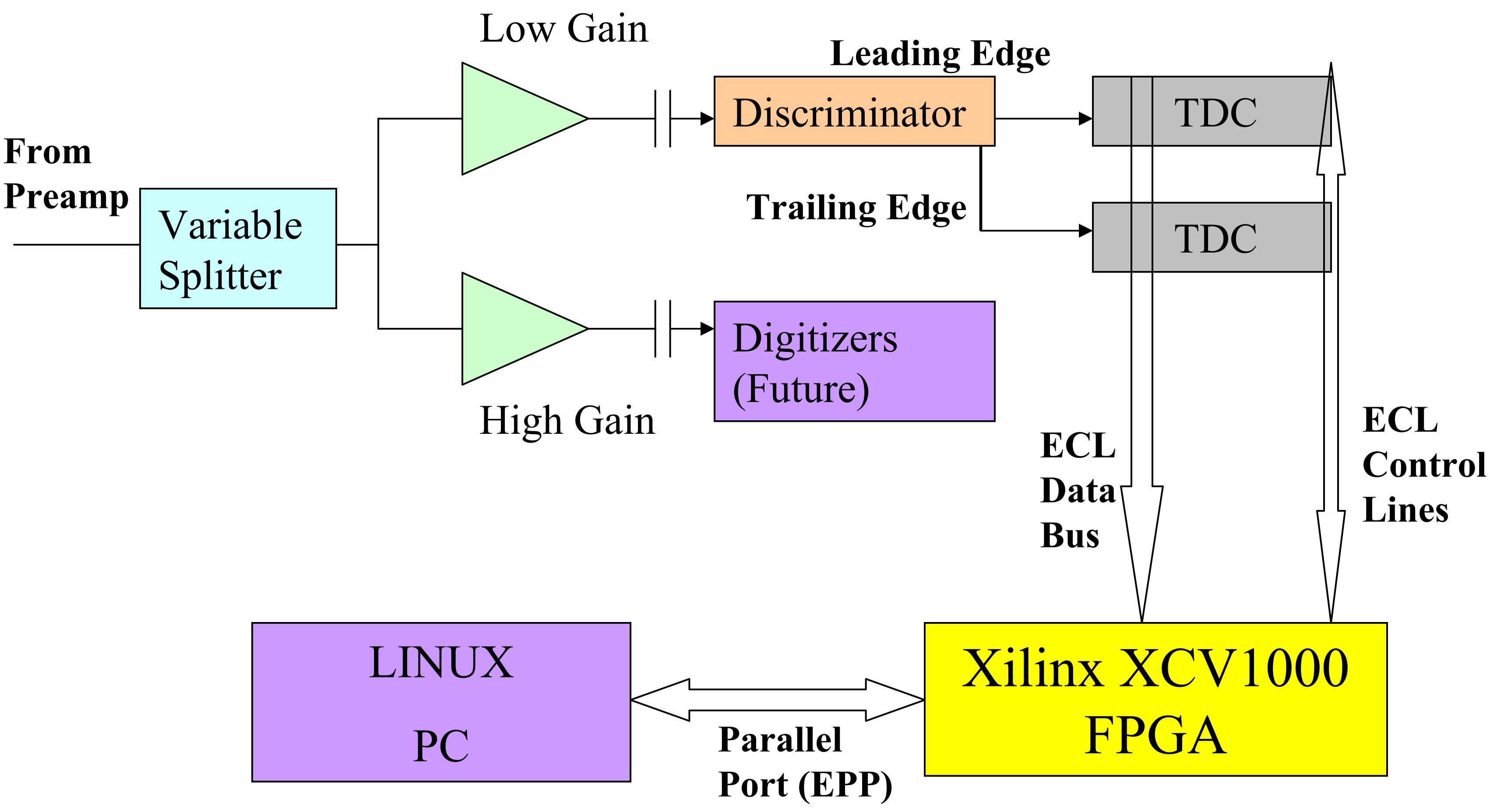
Pulse height measurement

Commercial digitizer chips (flash ADCs) are improving a rate of ~x2 in sampling speed every 2-3 years and the cost per chip for a fixed sampling speed is dropping at a similar rate. Hence, 2 GHz chips will be ~ $10/channel in about 4-6 years.

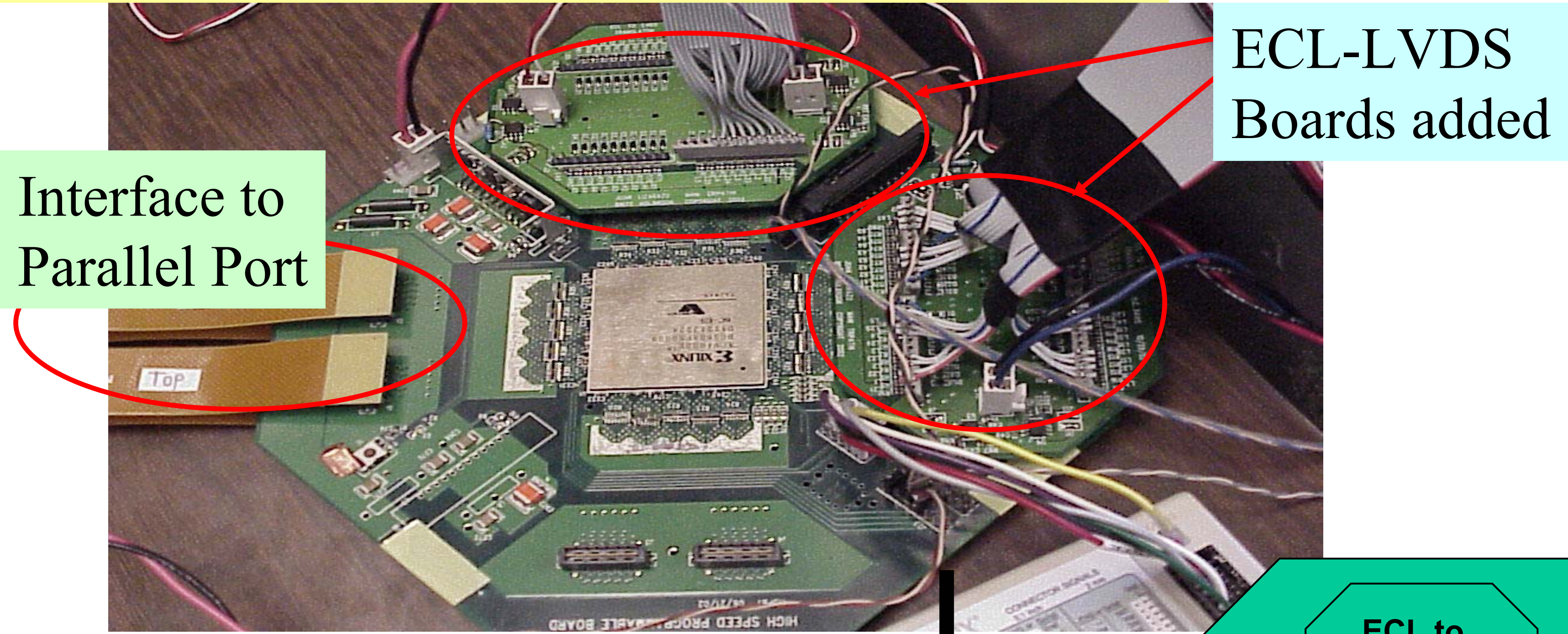
However, for the prototype system we can also use time-over-threshold measurements using the TDC readout.

Prototype Readout Schematic

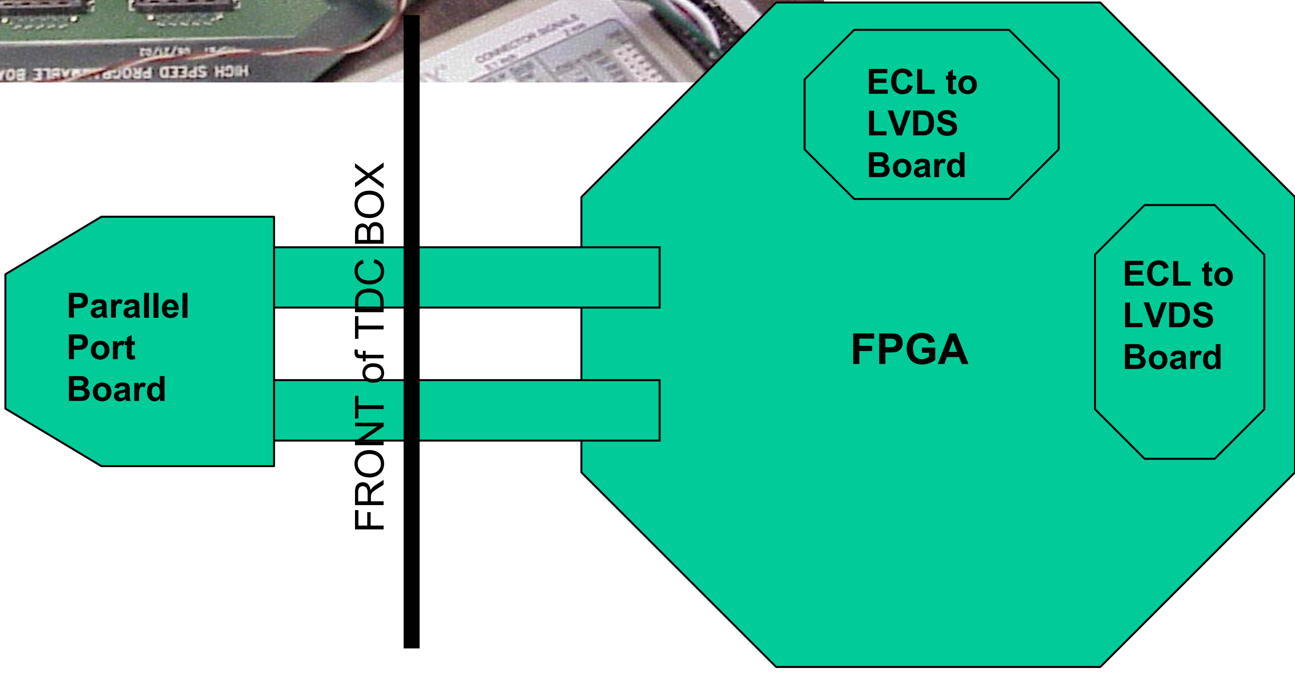
Implemented to overcome readout speed limitations of CAMAC and to provide a system with interface to Linux based C language programs.



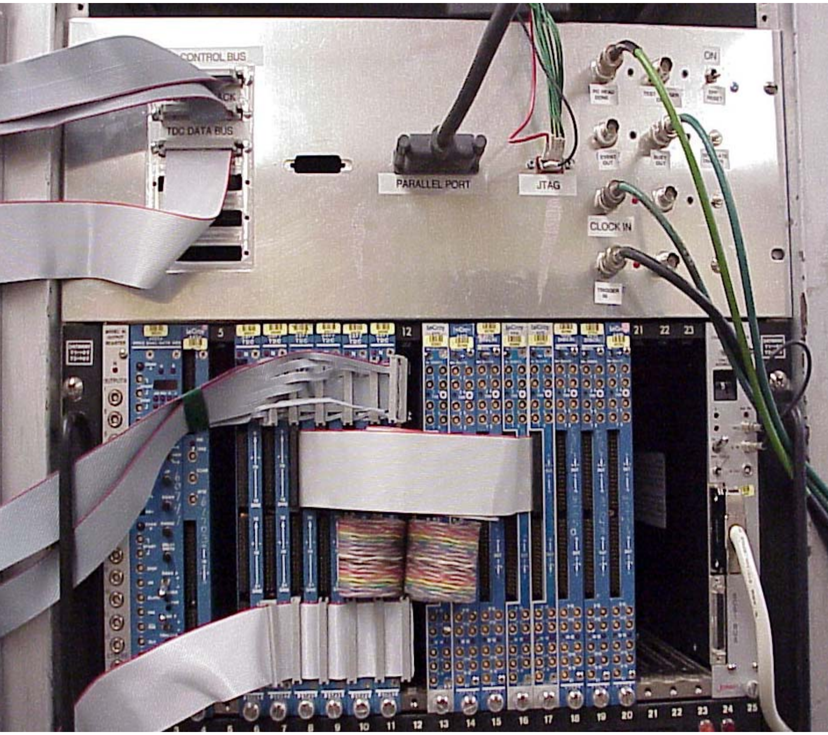
FPGA board used in TDC Readout

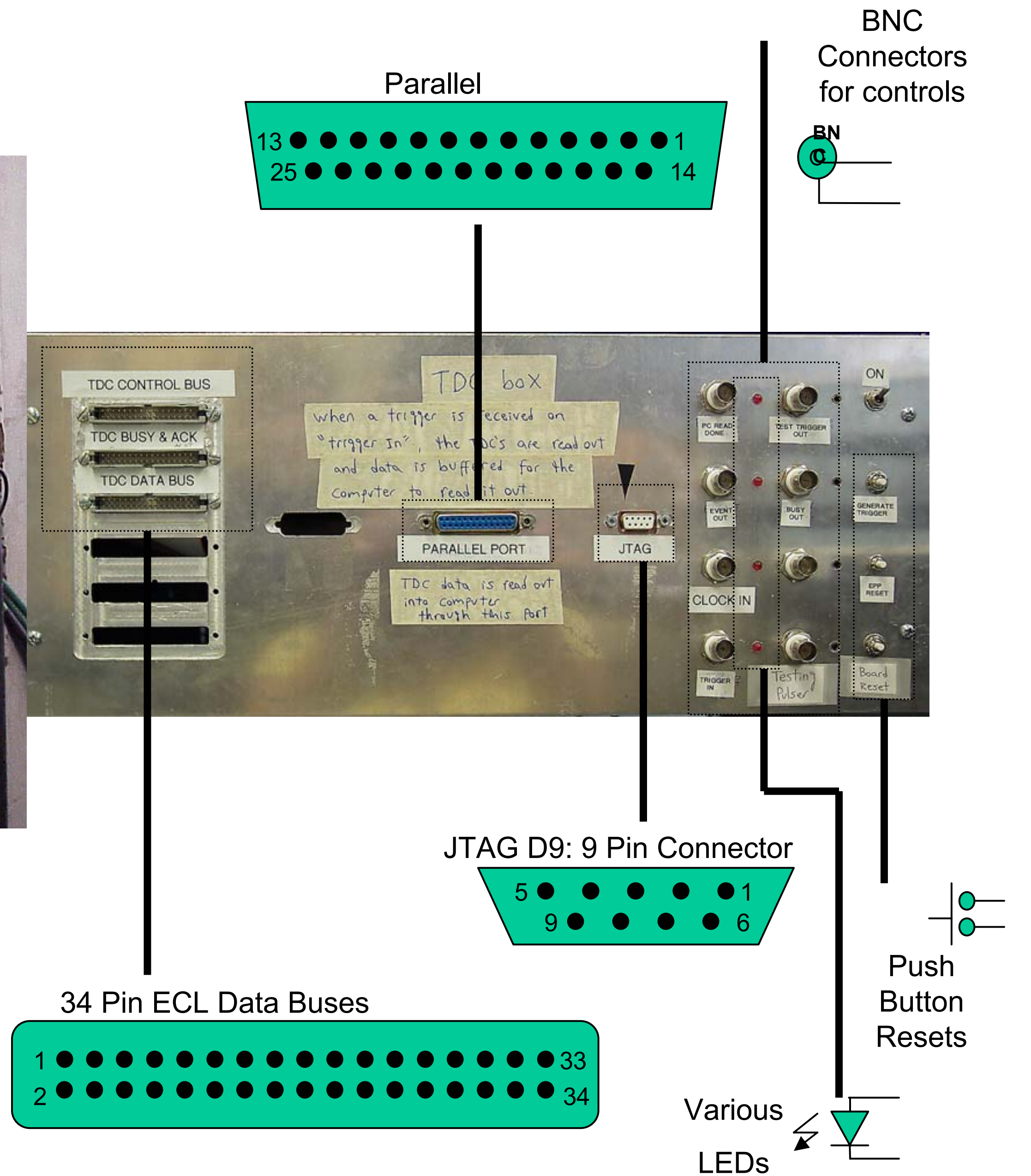


This FPGA board was developed as a generic programmable device. Various auxiliary boards make it application specific.



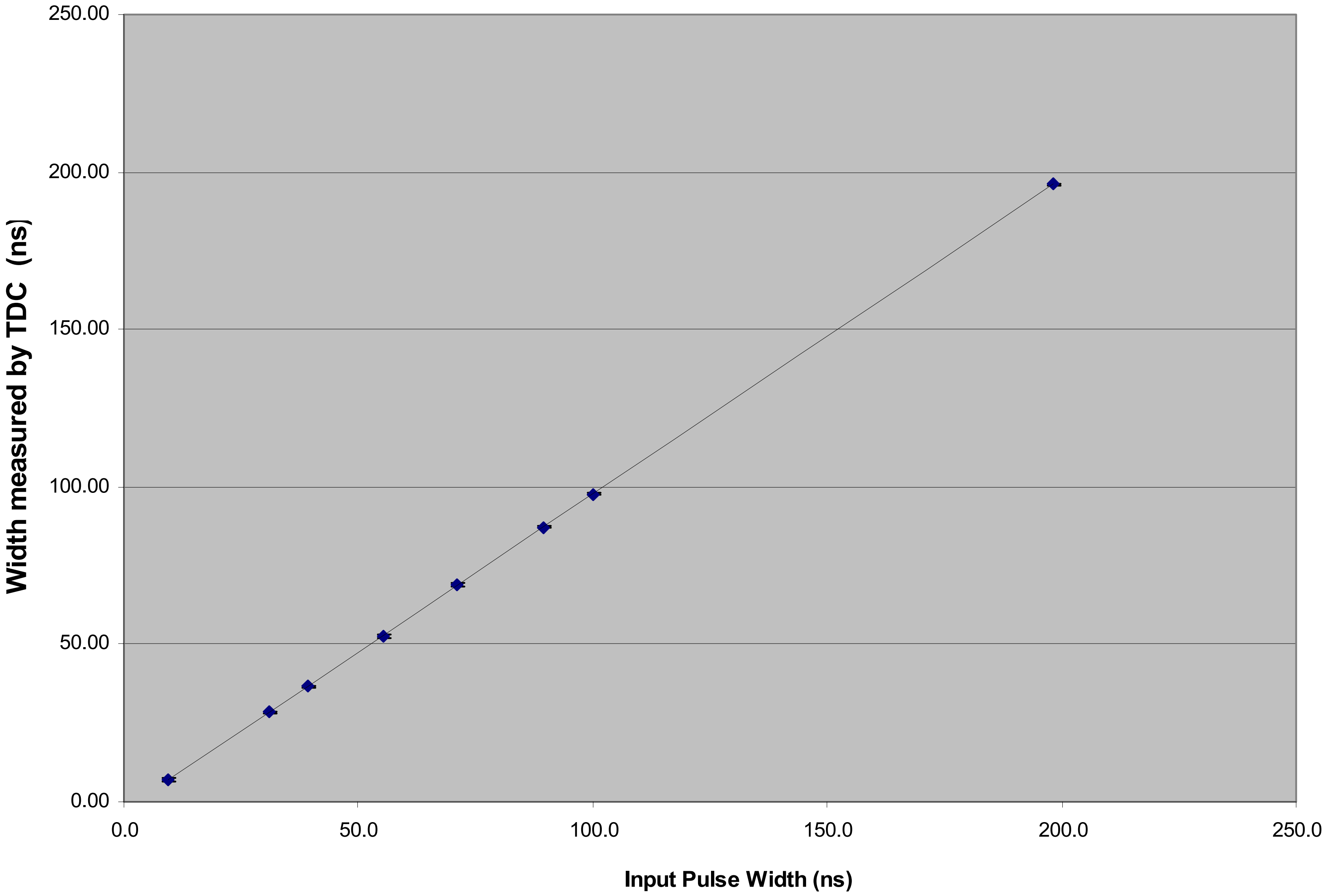
TDC Readout Set-up





The readout assembly is housed in a rack-mountable user-friendly box with manual controls to override software functions.

Time-over-Threshold Measurements



The pulse width is measured faithfully. The small systematic error is in the input PW.

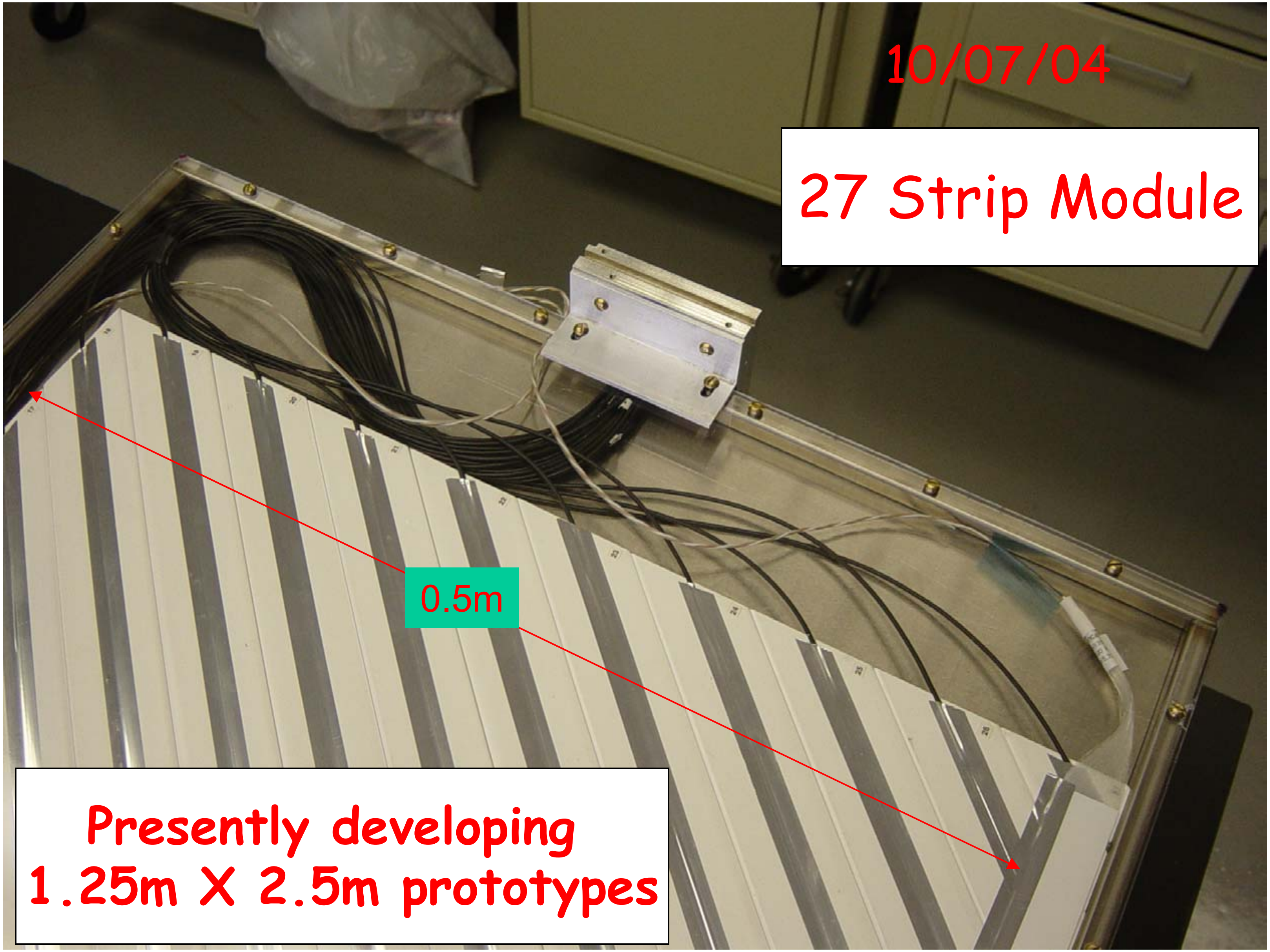
Digitization/Readout Summary

•Amplification system for the Hamamatsu 16-channel PMT has been developed.

•A DAQ for TDC modules has been developed for the test-stand.

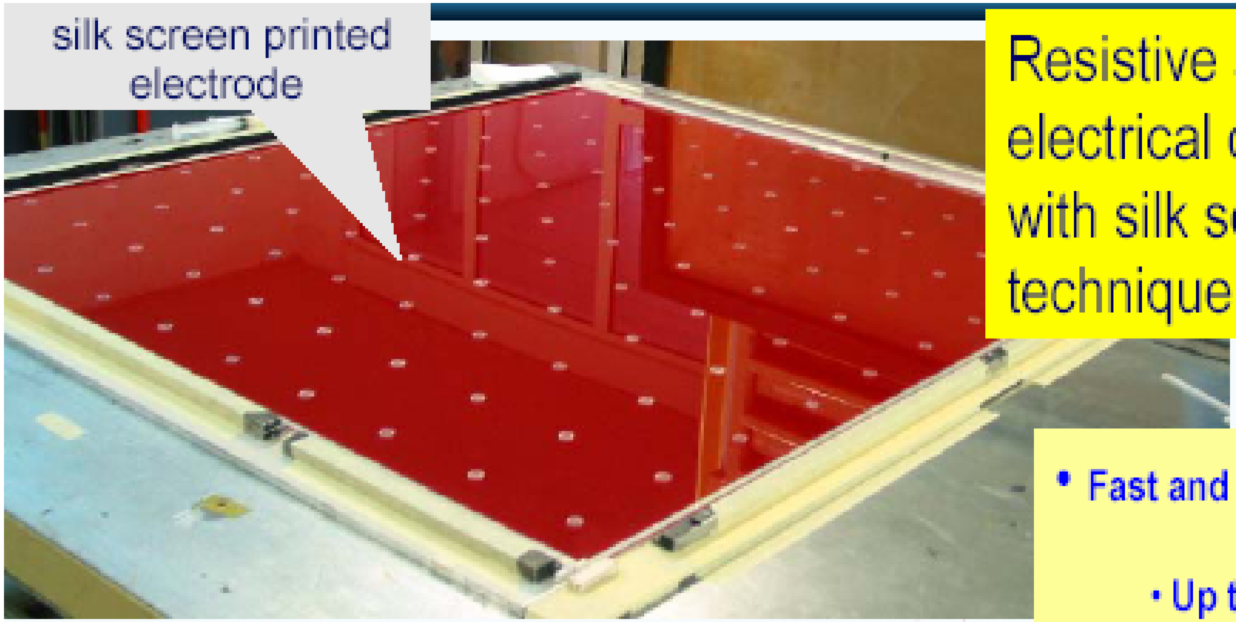
•A digitization and acquisition system is being designed for implementation in in the future.

0.5m X 1.0m Prototype – Assembled at Notre Dame



Glass Electrode RPC R&D at INFN

8 RPC's produced 1.1m X 1.0m CaPiRe Collab.



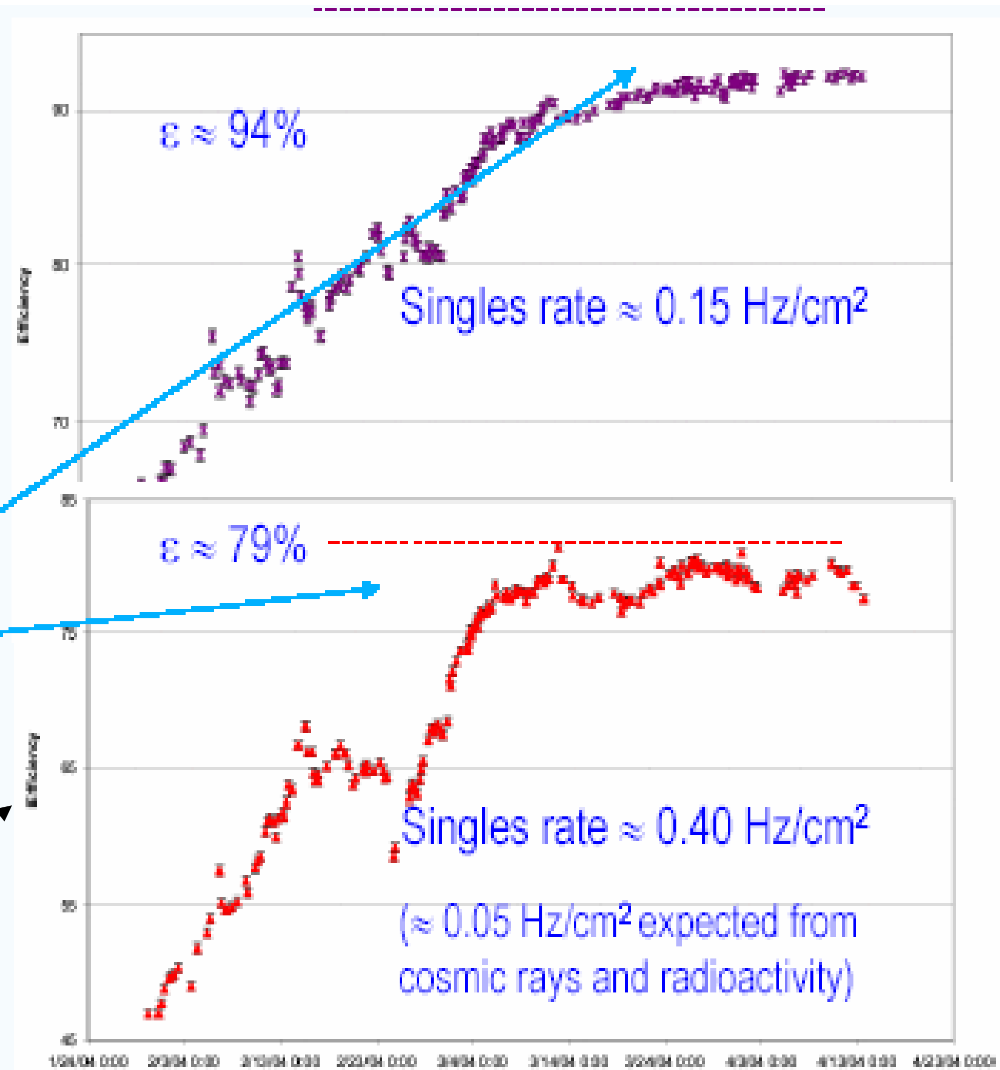
Resistive acrylic paint for electrical contacts deposited with silk screen printing technique

- Fast and reliable:
  - Up to 1000 m^2/day
  - Controllable and reproducible surface resistivity

G.C. Trinchero, A. Giuliano, P.Picchi, Nucl. Instr. and Meth. A 508 (2003) 102
M.Ambrosio et al. Nucl. Instr. and Meth. A 508 (2003) 98.

Efficiency Dependence on Rate Studies: glass industry involvement

- Stainless steel/copper tubing
  - dry gas (H_2O<50 ppm)
- More quenched gas mix ($Ar/C_2H_2F_4/i\text{-}C_4H_{10}$=27/64/9)
  - lower charge in the spark (catalyst of HF formation)
- (Partial) recovery of damaged chambers
- New chambers under study
  - → Test the chamber lifetime



Beam Test Data

Geiger Mode Avalanche Photodiode

Colo. State Univ. – R. Wilson & D.Warner

- Solid-state device being developed by aPeak Technology (SBIR contract).
- Tested with Y-11 WLS fiber connected to GPD.
- Measured dark current, rate vs. bias voltage, etc.
- Goal is a 64 channel device.
- High dark current makes measurement of detection efficiency difficult.

Further Muon System R&D Topics

- Scintillator strip calibration w/fiber ribbons.
- Calibration using LEDs.
- Precision tracking chambers at FE of muon system?
- Necessary precision for muon system calorimetry.
- Barrel Fe layout, engineering, cost, etc.
- Benchmark physics studies for the muon system.
- Forward muon physics case.
- Forward muon system design.
- Understanding muon backgrounds.
- Prototype module testing with cosmic rays and beam.

http://www-d0.fnal.gov/~maciel/LCD/awg_lcdmu.html